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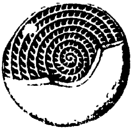
Gouzzl

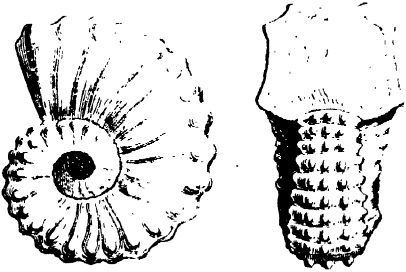
FRONTISPIECE

TERTIARY or CAINOZOIC



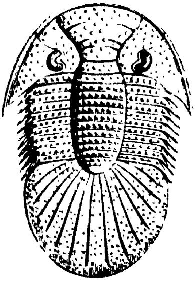
Nummulites lævigata

SECONDARY or MESOZOIC



Ammonites Rhotomagensis

PRIMARY or PALEOZOIC



Bronteus flabellifer

THE

STUDENT'S
ELEMENTS OF GEOLOGY

By Sir CHARLES LYELL, Bart., F.R.S.

AUTHOR OF
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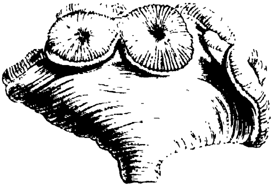
ETC.



Thecosmilia annularis

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WITH A NEW TABLE OF BRITISH FOSSILS
AND MORE THAN 600 ILLUSTRATIONS

LONDON
JOHN MURRAY, ALBEMARLE STREET
1874

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PREFACE.

Between the years 1838 and 1865 I published six editions of the 'Elements of Geology,' beginning with a small duodecimo volume, which increased with each successive edition, as new facts accumulated, until in 1865 it had become a large and somewhat expensive work.

When a seventh edition was called for, I was strongly urged by my friends to attempt to bring the book back again to a size more approaching the original, so that it might be within the reach of the ordinary student. In order to do this I resolved, in the first place, to omit some theoretical discussions which belonged more properly to my 'Principles of Geology,' and further to confine myself to examples of British rocks, wherever this could be done; only seeking foreign illustrations when, as in the case of the Upper Miocene or Falunian Tertiaries, no good representatives were to be found in this country.

I therefore published in 1871 what was substantially a new work under the title of 'The Student's Elements of Geology,' and the success of the attempt has been proved by the steady demand which has exhausted an unusually large edition in less than three years.

The present work has been carefully revised and corrected, with the addition of such new matter as the plan of the volume permitted.

I have also added a new and very important table (see p. 623) illustrative of the successive appearance and development in time, of the different forms of animal and vegetable life throughout the British fossiliferous rocks. This table has been compiled for me by Mr. Etheridge of the London School of Mines, from materials which he has been collecting for many years.

Among the numerous scientific friends who have rendered me valuable assistance in different parts of this new edition, I should wish especially to mention Mr. Searles Wood, Mr. David Forbes, Mr. Judd, and the Rev. T. G. Bonney, of St. John's, Cambridge.

CHARLES LYELL.

73 HARLEY STREET:
February 1874.

As it is impossible to enable the reader to recognise rocks and minerals at sight by aid of verbal descriptions or figures, he will do well to obtain a well-arranged collection of specimens such as may be procured from Mr. Tennant (149 Strand), teacher of Mineralogy at King's College, London.

CONTENTS.

CHAPTER I.

ON THE DIFFERENT CLASSES OF ROCKS.

Geology defined—Successive formation of the earth's crust—Classification of rocks according to their origin and age—Aqueous rocks—Their stratification and imbedded fossils—Volcanic rocks, with and without cones and craters—Plutonic rocks, and their relation to the volcanic—Metamorphic rocks, and their probable origin—The term primitive, why erroneously applied to the crystalline formations—Leading division of the work PAGE 1

CHAPTER II.

AQUEOUS ROCKS—THEIR COMPOSITION AND FORMS OF STRATIFICATION.

Mineral composition of strata—Siliceous rocks—Argillaceous—Calcareous—Gypsum—Forms of stratification—Original horizontality—Thinning out—Diagonal arrangement—Ripple mark 11

CHAPTER III.

ARRANGEMENT OF FOSSILS IN STRATA—FRESHWATER AND MARINE.

Successive deposition indicated by fossils—Limestones formed of corals and shells—Proofs of gradual increase of strata derived from fossils—Serpula attached to spatangus—Wood bored by teredina—Tripoli formed of infusoria—Chalk derived principally from organic bodies—Distinction of freshwater from marine formations—Genera of freshwater and land shells—Rules for recognising marine testacea—Gyrogonite and chara—Freshwater fishes—Alternation of marine and freshwater deposits—Lym-Fiord . 23

CHAPTER IV.

CONSOLIDATION OF STRATA AND PETRIFACTION OF FOSSILS.

Chemical and mechanical deposits—Cementing together of particles—Hardening by exposure to air—Concretionary nodules—Consolidating effects of pressure—Mineralisation of organic remains—Impressions and casts, how formed—Fossil wood—Göppert's experiments—Precipitation of stony matter most rapid where putrefaction is going on—Sources of lime and silex in solution . . . . . . PAGE 37

CHAPTER V.

ELEVATION OF STRATA ABOVE THE SEA—HORIZONTAL AND INCLINED STRATIFICATION.

Why the position of marine strata, above the level of the sea, should be referred to the rising up of the land, not to the going down of the sea—Strata of deep-sea and shallow-water origin alternate—Also marine and freshwater beds and old land surfaces—Vertical, inclined, and folded strata—Anticlinal and synclinal curves—Theories to explain lateral movements—Creeps in coal mines—Dip and strike—Structure of the Jura—Various forms of outcrop—Synclinal strata forming ridges—Connection of fracture and flexure of rocks—Inverted strata—Faults described—Superficial signs of the same obliterated by denudation—Great faults the result of repeated movements—Arrangement and direction of parallel folds of strata—Unconformability—Overlapping strata 47

CHAPTER VI.

DENUDATION.

Denudation defined—Its amount more than equal to the entire mass of stratified deposits in the earth's crust—Subaërial denudation—Action of the wind—Action of running water—Alluvium defined—Different ages of alluvium—Denuding power of rivers affected by rise or fall of land—Littoral denudation—Inland sea-cliffs—Escarpments—Submarine denudation—Dogger-bank—Newfoundland bank—Denuding power of the ocean during emergence of land 73

CHAPTER VII.

JOINT ACTION OF DENUDATION, UPHEAVAL, AND SUBSIDENCE IN REMODELLING THE EARTH'S CRUST.

How we obtain an insight at the surface, of the arrangement of rocks at great depths—Why the height of the successive strata in a given region is so disproportionate to their thickness—Computation of the average annual amount of subaërial denudation—Antagonism of volcanic force to the levelling power of running water—How far the transfer of sediment from the land to a neighbouring sea-bottom may affect subterranean movements—Permanence of continental and oceanic areas . PAGE 85

CHAPTER VIII.

CHRONOLOGICAL CLASSIFICATION OF ROCKS.

Aqueous, plutonic, volcanic, and metamorphic rocks considered chronologically—Terms Primary, Secondary, and Tertiary; Palæozoic, Mesozoic, and Cainozoic explained—On the different ages of the aqueous rocks—Three principal tests of relative age: superposition, mineral character, and fossils—Change of mineral character and fossils in the same continuous formation—Proofs that distinct species of animals and plants have lived at successive periods—Distinct provinces of indigenous species—Great extent of single provinces—Similar laws prevailed at successive geological periods—Relative importance of mineral and palæontological characters—Test of age by included fragments—Frequent absence of strata of intervening periods—Tabular views of fossiliferous strata . . 98

CHAPTER IX.

CLASSIFICATION OF TERTIARY FORMATIONS.

Order of succession of sedimentary formations—Frequent unconformability of strata—Imperfection of the record—Defectiveness of the monuments greater in proportion to their antiquity—Reasons for studying the newer groups first—Nomenclature of formations—Detached Tertiary formations scattered over Europe—Value of the shell-bearing mollusca in classification—Classification of Tertiary strata—Eocene, Miocene, and Pliocene terms explained 114

CHAPTER X.

RECENT AND PLEISTOCENE PERIODS.

Recent and Pleistocene periods—Terms defined—Formations of the Recent Period—Modern littoral deposits containing works of art near Naples—Danish peat and shell mounds—Swiss lake-dwellings—Periods of stone, bronze, and iron—Pleistocene formations—Coexistence of man with extinct mammalia—Reindeer period of South of France—Alluvial deposits of Paleolithic age—Higher and Lower-level Valley-gravels—Loess or inundation mud of the Nile, Rhine, &c.—Origin of caverns—Remains of man and extinct quadrupeds in cavern deposits—Cave of Kirkdale—Australian cave-breccias—Geographical relationship of the provinces of living vertebrata and those of extinct Pleistocene species—Extinct struthious birds of New Zealand—Climate of the Pleistocene period—Comparative longevity of species in the mammalia and testacea—Teeth of Recent and Pleistocene mammalia 122

CHAPTER XI.

PLEISTOCENE PERIOD, *continued*.—GLACIAL CONDITIONS.

Geographical distribution, form, and characters of glacial drift—Fundamental rocks, polished, grooved, and scratched—Abrading and striating action of glaciers—Moraines, erratic blocks, and 'Roches Moutonnées'—Alpine blocks on the Jura—Continental ice of Greenland—Ancient centres of the dispersion of erratics—Transportation of drift by floating icebergs—Bed of the sea furrowed and polished by the running aground of floating ice-islands . . . . PAGE 144

CHAPTER XII.

PLEISTOCENE PERIOD, *continued*.—GLACIAL CONDITIONS,

Glaciation of Scandinavia and Russia—Glaciation of Scotland—Mammoth in Scotch till—Marine shells in Scotch glacial drift—Their Arctic character—Rarity of organic remains in glacial deposits—Contorted strata in drift—Glaciation of Wales, England, and Ireland—Marine shells of Moel Tryfaen—Erratics near Chichester—Glacial formations of North America—Many species of testacea and quadrupeds survived the glacial cold—Connection of the predominance of lakes with glacial action—Action of ice in preventing the silting up of lake-basins—Absence of lakes in the Caucasus—Equatorial lakes of Africa 154

CHAPTER XIII.

PLIOCENE PERIOD.

Glacial formations of Pliocene age—Bridlington beds—Glacial drifts of Ireland—Drift of Norfolk cliffs—Cromer forest-bed—Aldeby and Chillesford beds—Norwich Crag—Older Pliocene strata—Red Crag of Suffolk—Coprolitic bed of Red Crag—White or Coralline Crag—Relative age, origin, and climate of the Crag deposits—Antwerp Crag—Newer Pliocene strata of Sicily—Newer Pliocene strata of the Upper Val d'Arno—Older Pliocene of Italy—Subapennine strata—Older Pliocene flora of Italy 169

CHAPTER XIV.

MIOCENE PERIOD—UPPER MIOCENE.

Upper Miocene strata of France—Faluns of Touraine—Tropical climate implied by testacea—Proportion of recent species of shells—Faluns more ancient than the Suffolk Crag—Upper Miocene of Bordeaux and the South of France—Upper Miocene of Œningen in Switzerland—Plants of the Upper freshwater Molasse—Fossil fruit and flowers as well as leaves—

Insects of the Upper Molasse—Middle or Marine Molasse of Switzerland —Upper Miocene beds of the Bolderberg in Belgium—Vienna basin—Upper Miocene of Italy and Greece—Upper Miocene of India; Siwâlik hills—Older Pliocene and Miocene of the United States . PAGE 192

CHAPTER XV.

LOWER MIOCENE.

Lower Miocene strata of France—Line between Miocene and Eocene—Lacustrine strata of Auvergne—Fossil mammalia of the Limagne d'Auvergne—Lower Molasse of Switzerland—Dense conglomerates and proofs of subsidence—Flora of the Lower Molasse—American character of the Flora—Theory of a Miocene Atlantis—Lower Miocene of Belgium—Rupelian clay of Hermsdorf near Berlin—Mayence Basin—Lower Miocene of Croatia—Oligocene strata of Beyrich—Lower Miocene of Italy—Lower Miocene of England—Hempstead beds—Bovey Tracey lignites in Devonshire—Isle of Mull leaf-beds—Arctic Miocene Flora—Disco Island—Lower Miocene of United States—Fossils of Nebraska . . 213

CHAPTER XVI.

EOCENE FORMATIONS.

Eocene areas of north of Europe—Table of English and French Eocene strata—Upper Eocene of England—Bembridge beds—Osborne or St. Helen's beds—Headon series—Fossils of the Barton sands and clays—Middle Eocene of England—Shells, nummulites, fish, and reptiles of the Bracklesham beds and Bagshot sands—Plants of Alum Bay and Bournemouth—Lower Eocene of England—London Clay fossils—Woolwich and Reading beds formerly called 'Plastic Clay'—Fluviatile beds underlying deep-sea strata—Thanet sands—Upper Eocene strata of France—Gypseous series of Montmartre and extinct quadrupeds—Fossil footprints in Paris gypsum—Imperfection of the Record—Calcaire siliceux—Grés de Beauchamp—Calcaire grossier—Miliolite limestone—Soissonnais sands—Lower Eocene of France—Nummulitic formations of Europe, Africa, and Asia—Eocene strata in the United States—Gigantic cetacean . . 233

CHAPTER XVII.

UPPER CRETACEOUS GROUP.

Lapse of time between Cretaceous and Eocene periods—Table of successive Cretaceous formations—Maestricht beds—Pisolitic limestone of France—Chalk of Faxoe—Geographical extent and origin of the White Chalk—Chalky matter now forming in the bed of the Atlantic—Marked difference between the Cretaceous and existing fauna—Chalk flints—Potstones of Horstead—Vitreous sponges in the Chalk—Isolated blocks of foreign rocks in the white chalk, supposed to be iceborne—Distinctness of mineral character in contemporaneous rocks of the Cretaceous epoch—Fossils of the white chalk—Lower white chalk without flints—Chalk Marl and its fossils—Chloritic series or Upper Greensand—Coprolite bed near Cambridge—Fossils of the Chloritic series—Gault—Connection between Upper and Lower Cretaceous strata—Blackdown beds—Flora of the Upper Cretaceous Period—Hippurite Limestone—Cretaceous rocks in the United States . . . . PAGE 264

CHAPTER XVIII.

LOWER CRETACEOUS OR NEOCOMIAN FORMATION.

Classification of marine and freshwater strata—Upper Neocomian—Folkestone and Hythe beds—Atherfield clay—Similarity of conditions causing reappearance of species after short intervals—Upper Speeton clay—Middle Neocomian—Tealby series—Middle Speeton clay—Lower Neocomian—Lower Speeton clay—Wealden formation—Freshwater character of the Wealden—Weald clay—Hastings sand—Punfield beds of Purbeck, Dorsetshire—Fossil shells and fish of the Wealden—Area of the Wealden—Flora of the Wealden 292

CHAPTER XIX.

JURASSIC GROUP.—PURBECK BEDS AND OOLITE.

The Purbeck beds a member of the Jurassic group—Subdivisions of that group—Physical geography of the Oolite in England and France—Upper Oolite—Purbeck beds—New genera of fossil mammalia in the Middle Purbeck of Dorsetshire—Dirt-bed or ancient soil—Fossils of the Purbeck beds—Portland stone and fossils—Kimmeridge clay—Lithographic stone of Solenhofen—Archæopteryx—Middle Oolite—Coral rag—Nerinæa limestone—Oxford Clay, Ammonites and Belemnites—Kelloway Rock—Lower, or Bath Oolite—Great plants of the Oolite—Oolite and Bradford clay—Stonesfield slate—Fossil mammalia—Fuller's earth—Inferior Oolite and fossils—Northamptonshire slates—Yorkshire Oolitic coal-field—Brora coal—Palæontological relations of the several subdivisions of the Oolitic group 307

CHAPTER XX.

JURASSIC GROUP—*continued.* LIAS.

Mineral character of Lias—Numerous successive Zones in the Lias, marked by distinct fossils, without unconformity in the stratification, or change in the mineral character of the deposits—Gryphite limestone—Shells of the Lias—Fish of the Lias—Reptiles of the Lias—Ichthyosaur and Plesiosaur—Marine Reptile of the Galapagos Islands—Sudden destruction and burial of fossil animals in Lias—Fluvio-marine beds in Gloucestershire, and insect limestone—Fossil plants—Origin of the Oolite and Lias, and of alternating calcareous and argillaceous formations 340

CHAPTER XXI.

TRIAS, OR NEW RED SANDSTONE GROUP.

Beds of passage between the Lias and Trias, Rhætic beds—Triassic mammifer—Triple division of the Trias—Keuper, or Upper Trias of England—Reptiles of the Upper Trias—Footprints in the Bunter formation in England—Dolomitic conglomerate of Bristol—Origin of Red Sandstone and Rock-salt—Precipitation of salt from inland lakes and lagoons—Trias of Germany—Keuper—St. Cassian and Hallstadt beds—Peculiarity of their fauna—Muschelkalk and its fossils—Trias of the United States—Fossil footprints of birds and reptiles in the valley of the Connecticut—Triassic mammifer of North Carolina—Triassic coal-field of Richmond, Virginia—Low grade of early mammals favourable to the theory of progressive development . . . . PAGE 354

CHAPTER XXII.

PERMIAN OR MAGNESIAN LIMESTONE GROUP.

Line of separation between Mesozoic and Palæozoic rocks—Distinctness of Triassic and Permian fossils—Term Permian—Thickness of calcareous and sedimentary rocks in North of England—Upper—Middle—and Lower Permian—Marine shells and corals of the English Magnesian Limestone—Reptiles and fish of Permian marl slate—Footprints of reptiles—Angular breccias in Lower Permian—Extent of land in the Permian Period—Permian rocks of the Continent—Zechstein and Rothliegendes of Thuringia—Permian flora—Its generic affinity with the Carboniferous . 375

CHAPTER XXIII.

THE COAL OR CARBONIFEROUS GROUP.

Principal subdivisions of the Carboniferous Group—Different thickness of the sedimentary and calcareous members in Scotland and the South of England—Coal-measures—Terrestrial nature of the growth of coal—Erect fossil trees—Uniting of many coal-seams into one thick bed—Purity of the coal explained—Conversion of coal into anthracite—Origin of clay ironstone—Marine and brackish-water strata in coal—Fossil insects—Batrachian reptiles—Carboniferous Amphibia—Labyrinthodont footprints in coal-measures—Nova Scotia coal-measures with successive growths of erect fossil trees—Structure of American and European coal—Air-breathers of the American coal—Changes of condition of land and sea indicated by the Carboniferous strata of Nova Scotia 385

CHAPTER XXIV.

FLORA AND FAUNA OF THE CARBONIFEROUS PERIOD.

Vegetation of the Coal period—Ferns, Lycopodiaceæ, Equisetaceæ, Sigillariæ, Stigmariæ, Coniferæ—Monocotyledon of the coal-measures—Climate of the Coal period—Mountain Limestone—Marine Fauna of the Carboniferous Period—Corals—Polyzoa, Crinoidea—Mollusca—Great number of fossil fish—Foraminifera . . . . . . PAGE 413

CHAPTER XXV.

DEVONIAN OR OLD RED SANDSTONE GROUP.

Classification of the Old Red Sandstone in Scotland and in Devonshire—Upper Old Red Sandstone in Scotland, with fish and plants—Middle Old Red Sandstone—Classification of the Ichthyolites of the Old Red, and their relation to living types—Lower Old Red Sandstone, with *Cephalapsis* and *Pterygotus*—Marine or Devonian type of Old Red Sandstone—Table of Devonian series—Upper Devonian rocks and fossils—Middle—Lower—Eifel Limestone of Germany—Devonian of Russia—Devonian Strata of the United States and Canada—Devonian Plants and Insects of Canada 434

CHAPTER XXVI.

SILURIAN GROUP.

Classification of the Silurian rocks—Ludlow formation and fossils—Bone-bed of the Upper Ludlow—Lower Ludlow shales with *Pentamerus*—Oldest known remains of fossil fish—Table of the progressive discovery of vertebrata in older rocks—Wenlock formation, corals, cystideans, and trilobites—Llandovery group or beds of passage—Lower Silurian rocks—Caradoc and Bala Beds—Brachiopoda—Trilobites—Cystideæ—Graptolites—Llandeilo Flags—Arenig or Stiper-stones group—Foreign Silurian equivalents in Europe—Barrande's Silurian fauna—Silurian strata of the United States—Canadian equivalents—Amount of specific agreement of fossils with those of Europe 455

CHAPTER XXVII.

CAMBRIAN AND LAURENTIAN GROUPS.

Classification of the Cambrian group, and its equivalent in Bohemia—Upper Cambrian rocks—Tremadoc slates and their fossils—Lingula Flags—Lower Cambrian rocks—Menevian Beds—Longmynd group—Harlech grits with large Trilobites—Llanberis slates—Cambrian rocks of Bohemia—Primordial zone of Barrande—Metamorphosis of Trilobites—Cambrian Rocks of Sweden and Norway—Cambrian Rocks of the United States and Canada—Potsdam sandstone—Huronian series—Laurentian group, upper and lower—*Eozoon Canadense*, oldest known fossil—Fundamental gneiss of Scotland 480

CHAPTER XXVIII.

VOLCANIC ROCKS.

External form, structure, and origin of volcanic mountains—Cones and craters—Hypothesis of 'elevation craters' considered—Trap rocks—Name whence derived—Minerals most abundant in volcanic rocks—Table of the analysis of minerals in the Volcanic and Hypogene rocks—Similar minerals in meteorites—Theory of Isomorphism—Basaltic rocks—Trachytic rocks—Special forms of structure—The columnar and globular forms—Trap dikes and veins—Alteration of rocks by volcanic dikes—Conversion of chalk into marble—Intrusion of trap between strata—Relation of trappean rocks to the products of active volcanos . PAGE 493

CHAPTER XXIX.

ON THE AGES OF VOLCANIC ROCKS.

Tests of relative age of volcanic rocks—Why ancient and modern rocks cannot be identical—Tests by superposition and intrusion—Test by alteration of rocks in contact—Test by organic remains—Test of age by mineral character—Test by included fragments—Post-Tertiary volcanic rocks—Vesuvius, Auvergne, Puy de Côme, and Puy de Pariou—Newer Pliocene volcanic rocks—Cyclopean Isles, Etna, Dikes of Patagonia, Madeira—Older Pliocene volcanic rocks—Italy—Pliocene volcanos of the Eifel—Trass 520

CHAPTER XXX.

AGE OF VOLCANIC ROCKS—*continued.*

Volcanic rocks of the Upper Miocene Period—Madeira—Grand Canary—Azores—Lower Miocene volcanic rocks—Isle of Mull—Staffa and Antrim—The Eifel—Upper and Lower Miocene volcanic rocks of Auvergne—Hill of Gergovia—Eocene volcanic rocks of the Hebrides—Of Monte Bolca—Trap of Cretaceous Period—Oolitic Period—Triassic Period—Permian Period—Carboniferous Period—Erect trees buried in volcanic ash in the Island of Arran—Old Red Sandstone Period—Silurian Period—Cambrian Period—Laurentian volcanic rocks . . . 536

CHAPTER XXXI.

PLUTONIC ROCKS.

General aspect of plutonic rocks—Granite and its varieties—Decomposing into spherical masses—Rude columnar structure—Graphic granite—Mutual penetration of crystals of quartz and felspar—Glass cavities in quartz of granite—Porphyritic, talcose, and hornblendic granite—Eurite—Syenite

—Diorite—Connection of the plutonic with the volcanic rocks—Analogy in composition of trachyte and granite—Granite veins in Glen Tilt, Cape of Good Hope, and Cornwall—Metalliferous veins in strata near their junction with granite—Quartz veins—Exposure of plutonic rocks at the surface due to denudation . . . . . PAGE 551

CHAPTER XXXII.

ON THE DIFFERENT AGES OF THE PLUTONIC ROCKS.

Difficulty in ascertaining the precise age of a plutonic rock—Test of age by relative position—Test by intrusion and alteration—Test by mineral composition—Test by included fragments—Recent and Pliocene plutonic rocks, why invisible—Miocene syenite of the Isle of Skye—Eocene plutonic rocks in the Andes—Granite altering Cretaceous rocks—Granite altering Lias in the Alps—Granite of Dartmoor altering Carboniferous strata—Granite of the Old Red Sandstone Period—Syenite altering Silurian strata in Norway—Blending of the same with gneiss—Most ancient plutonic rocks—Granite protruded in a solid form 565

CHAPTER XXXIII.

METAMORPHIC ROCKS.

General character of metamorphic rocks—Gneiss—Hornblende-schist—Serpentine—Mica-schist—Clay-slate—Quartzite—Chlorite-schist—Metamorphic limestone—Origin of the metamorphic strata—Their stratification—Fossiliferous strata near intrusive masses of granite converted into rocks identical with different members of the metamorphic series—Arguments hence derived as to the nature of plutonic action—Hydrothermal action, or the influence of steam and gases in producing metamorphism—Objections to the metamorphic theory considered 576

CHAPTER XXXIV.

METAMORPHIC ROCKS—*continued.*

Definition of slaty cleavage and joints—Supposed causes of these structures—Crystalline theory of cleavage—Mechanical theory of cleavage—Condensation and elongation of slate rocks by lateral pressure—Lamination of some volcanic rocks due to motion—Whether the foliation of the crystalline schists be usually parallel with the original planes of stratification—Examples in Norway and Scotland—Causes of irregularity in the planes of foliation 589

CHAPTER XXXV.

ON THE DIFFERENT AGES OF THE METAMORPHIC ROCKS.

Difficulty of ascertaining the age of metamorphic strata—Metamorphic strata of Eocene date in the Alps of Switzerland and Savoy—Limestone and shale of Carrara—Metamorphic strata of older date than the Silurian and Cambrian rocks—Order of succession in metamorphic rocks—Uniformity of mineral character—Supposed Azoic Period—Connection between the absence of organic remains and the scarcity of calcareous matter in metamorphic rocks . . . . . . PAGE 599

CHAPTER XXXVI.

MINERAL VEINS.

Different kinds of mineral veins—Ordinary metalliferous veins or lodes—Their frequent coincidence with faults—Proofs that they originated in fissures in solid rock—Veins shifting other veins—Polishing of their walls or 'slicken sides'—Shells and pebbles in lodes—Evidence of the successive enlargement and reopening of veins—Examples in Cornwall and in Auvergne—Dimensions of veins—Why some alternately swell out and contract—Filling of lodes by sublimation from below—Supposed relative age of the precious metals—Copper and lead veins in Ireland older than Cornish tin—Lead vein in lias, Glamorganshire—Gold in Russia, California, and Australia—Origin of mineral veins . . 607

TABLE OF BRITISH FOSSILS 622

INDEX 647

STUDENT'S

ELEMENTS OF GEOLOGY.

CHAPTER I.

ON THE DIFFERENT CLASSES OF ROCKS.

Geology defined—Successive formation of the earth's crust—Classification o rocks according to their origin and age—Aqueous rocks—Their stratification and imbedded fossils—Volcanic rocks, with and without cones and craters—Plutonic rocks, and their relation to the volcanic—Metamorphic rocks, and their probable origin—The term primitive, why erroneously applied to the crystalline formations—Leading division of the work.

Of what materials is the earth composed, and in what manner are these materials arranged? These are the first enquiries with which Geology is occupied, a science which derives its name from the Greek, γῆ, *ge*, the earth, and λόγος, *logos*, a discourse. Previously to experience we might have imagined that investigations of this kind would relate exclusively to the mineral kingdom, and to the various rocks, soils, and metals, which occur upon the surface of the earth, or at various depths beneath it. But, in pursuing such researches, we soon find ourselves led on to consider the successive changes which have taken place in the former state of the earth's surface and interior, and the causes which have given rise to these changes; and, what is still more singular and unexpected, we soon become engaged in researches into the history of the animate creation, or of the various tribes of animals and plants which have, at different periods of the past, inhabited the globe.

All are aware that the solid parts of the earth consist of distinct substances, such as clay, chalk, sand, limestone, coal, slate, granite, and the like; but previously to observation it is commonly imagined that all these have remained from the first in the state in which we now see them,—that they were created in their present form, and in their present position. The geologist soon comes to a different conclusion, discovering proofs that the external parts of the earth were not all produced in the beginning of things in the state in which we now behold them, nor in an instant of time. On the contrary, he can show that they have acquired their actual configuration and condition gradually, under a great variety of circumstances, and at successive periods, during each of which distinct races of living beings have flourished on the land and in the waters, the remains of these creatures still lying buried in the crust of the earth.

By the 'earth's crust,' is meant that small portion of the exterior of our planet which is accessible to human observation. It comprises not merely all of which the structure is laid open in mountain precipices, or in cliffs overhanging a river or the sea, or whatever the miner may reveal in artificial excavations; but the whole of that outer covering of the planet on which we are enabled to reason by observations made at or near the surface. These reasonings may extend to a depth of several miles, perhaps ten miles; and even then it may be said, that such a thickness is no more than $\frac{1}{400}$ part of the distance from the surface to the centre. The remark is just; but although the dimensions of such a crust are, in truth, insignificant when compared to the entire globe, yet they are vast, and of magnificent extent in relation to man, and to the organic beings which people our globe. Referring to this standard of magnitude, the geologist may admire the ample limits of his domain, and admit, at the same time, that not only the exterior of the planet, but the entire earth, is but an atom in the midst of the countless worlds surveyed by the astronomer.

The materials of this crust are not thrown together confusedly; but distinct mineral masses, called rocks, are found to occupy definite spaces, and to exhibit a certain order of arrangement. The term *rock* is applied indifferently by geologists to all these substances, whether they be soft or stony, for clay and sand are included in the term, and some have even brought peat under this denomination. Our old writers endeavoured to avoid offering such violence to our language, by speaking of the component materials of the earth as consisting of rocks and *soils*. But there is often so insensible a passage from a soft and incoherent state to that of stone, that geologists of all countries have found it indispensable to have one technical term to include both, and in this sense we find *roche* applied in French, *rocca* in Italian, and *felsart* in German. The beginner, however, must constantly bear in mind, that the term rock by no means implies that a mineral mass is in an indurated or stony condition.

The most natural and convenient mode of classifying the various rocks which compose the earth's crust, is to refer, in the first place to their origin, and in the second to their relative age. I shall therefore begin by endeavouring briefly to explain to the student how all rocks may be divided into four great classes by reference to their different origin, or, in other words, by reference to the different circumstances and causes by which they have been produced.

The first two divisions, which will at once be understood as natural, are the aqueous and volcanic, or the products of watery and those of igneous action at or near the surface.

Aqueous rocks.—The aqueous rocks, sometimes called the sedimentary, or fossiliferous, cover a larger part of the earth's surface than any others. They consist chiefly of mechanical deposits (pebbles, sand, and mud), but are partly of chemical and some of them of organic origin, especially the limestones. These rocks are *stratified*, or divided into distinct layers, or strata. The term *stratum* means simply a bed, or anything spread out or *strewed* over a given surface; and we infer that these strata have been generally spread out by the action of water, from what we daily see taking place near the mouths of rivers, or on the land during temporary inundations. For, whenever a running stream charged with mud or sand, has its velocity checked, as when it enters a lake or sea, or overflows a plain, the sediment, previously held in suspension by the motion of the water, sinks, by its own gravity, to the bottom. In this manner layers of mud and sand are thrown down one upon another.

If we drain a lake which has been fed by a small stream, we frequently find at the bottom a series of deposits, disposed with considerable regularity, one above the other; the uppermost, perhaps, may be a stratum of peat, next below a more dense and solid variety of the same material; still lower a bed of shell-marl, alternating with peat or sand, and then other beds of marl, divided by layers of clay. Now, if a second pit be sunk through the same continuous lacustrine *formation* at some distance from the first, nearly the same series of beds is commonly met with, yet with slight variations; some, for example, of the layers of sand, clay, or marl, may be wanting, one or more of them having thinned out and given place to others, or sometimes one of the masses first examined is observed to increase in thickness to the exclusion of other beds.

The term '*formation*,' which I have used in the above explanation, expresses in geology any assemblage of rocks which have some character in common, whether of origin, age, or composition. Thus we speak of stratified and unstratified, freshwater and marine, aqueous and volcanic, ancient and modern, metalliferous and non-metalliferous formations.

In the estuaries of large rivers, such as the Ganges and the Mississippi, we may observe, at low water, phenomena analogous to those of the drained lakes above mentioned, but on a grander scale, and extending over areas several hundred miles in length and breadth. When the periodical inundations subside, the river hollows out a channel to the depth of many yards through horizontal beds of clay and sand, the ends of which are seen exposed in perpendicular cliffs. These beds vary in their mineral composition, or colour, or in the fineness or coarseness of their particles, and some of them are occasionally characterised by containing drift wood. At the junction of the river and the sea, especially in lagoons nearly separated by sand bars from the ocean, deposits are often formed in which brackish- and salt-water shells are included.

In Egypt, where the Nile is always adding to its delta by filling up part of the Mediterranean with mud, the newly deposited sediment is *stratified*, the thin layer thrown down in one season differing slightly in colour from that of a previous year, and being separable from it, as has been observed in excavations at Cairo, and other places.[1]

When beds of sand, clay, and marl, containing shells and vegetable matter, are found arranged in a similar manner in the interior of the earth, we ascribe to them a similar origin; and the more we examine their characters in minute detail, the more exact do we find the resemblance. Thus, for example, at various heights and depths in the earth, and often far from seas, lakes, and rivers, we meet with layers of rounded pebbles composed of flint, limestone, granite, or other rocks, resembling the shingles of a sea-beach or the gravel in a torrent's bed. Such layers of pebbles frequently alternate with others formed of sand or fine sediment, just as we may see in the channel of a river descending from hills bordering a coast, where the current sweeps down at one season coarse sand and gravel, while at another, when the waters are low and less rapid, fine mud and sand alone are carried seaward.[2]

If a stratified arrangement, and the rounded form of pebbles, are alone sufficient to lead us to the conclusion that certain rocks originated under water, this opinion is further confirmed by the distinct and independent evidence of *fossils*, so abundantly included in the earth's crust. By a *fossil* is meant any body, or the traces of the existence of any body, whether animal or vegetable, which has been buried in the earth by natural causes. Now the remains of animals, especially of aquatic species, are found almost everywhere imbedded, in stratified rocks, and sometimes, in the case of limestone, they are in such abundance as to constitute the entire mass of the rock itself. Shells and corals are the most frequent, and with them are often associated the bones and teeth of fishes, fragments of wood, impressions of leaves, and other organic substances. Fossil shells, of forms such as now abound in the sea, are met with far inland, both near the surface, and at great depths below it. They occur at all heights above the level of the ocean, having been observed at elevations of more than 8,000 feet in the Pyrenees, 10,000 in the Alps, 13,000 in the Andes, and above 18,000 feet in the Himalaya.[1]

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[1] See Principles of Geology, by the Author, Index, 'Nile,' 'Rivers,' &c.

[2] See p. 20, fig. 7.

These shells belong mostly to marine testacea, but in some places exclusively to forms characteristic of lakes and rivers. Hence it is concluded that some ancient strata were deposited at the bottom of the sea, and others in lakes and estuaries.

We have now pointed out one great class of rocks, which, however they may vary in mineral composition, colour, grain, or other characters, external and internal, may nevertheless be grouped together as having a common origin. They have all been formed under water, in the same manner as modern accumulations of sand, mud, shingle, banks of shells, reefs of coral, and the like, and are all characterised by stratification or fossils, or by both.

Volcanic rocks.—The division of rocks which we may next consider are the volcanic, or those which have been produced at or near the surface whether in ancient or modern times, not by water, but by the action of fire or subterranean heat. These rocks are for the most part unstratified, and are devoid of fossils. They are more partially distributed than aqueous formations, at least in respect to horizontal extension. Among those parts of Europe where they exhibit characters not to be mistaken, I may mention not only Sicily and the country round Naples, but Auvergne, Velay, and Vivarais, now the departments of Puy de Dome, Haute Loire, and Ardêche, towards the centre and south of France, in which are several hundred conical hills having the forms of modern volcanos, with craters more or less perfect on many of their summits. These cones are composed moreover of lava, sand, and ashes, similar to those of active volcanos. Streams of lava may sometimes be traced from the cones into the adjoining valleys, where they have choked up the ancient channels of rivers with solid rock, in the same manner as some modern flows of lava in Iceland have been known to do, the rivers either flowing beneath or cutting out a narrow passage on one side of the lava. Although none of these French volcanos have been in activity within the period of history or tradition, their forms are often very perfect. Some, however, have been compared to the mere skeletons of volcanos, the rains and torrents having washed their sides, and removed all the loose sand and scoriæ, leaving only the harder and more solid materials. By this erosion, and by earthquakes, their internal structure has occasionally been laid open to view, in fissures and ravines; and we then behold not only many successive beds and masses of porous lava, sand, and scoriæ, but also perpendicular walls, or *dikes*, as they are called, of volcanic rock, which have burst through the other materials. Such dikes are also observed in the structure of Vesuvius, Etna, and other active volcanos. They have been formed by the pouring of melted matter, whether from above or below, into open fissures, and they commonly traverse deposits of *volcanic tuff*, a substance produced by the showering down from the air, or incumbent waters, of sand and cinders, first shot up from the interior of the earth by the explosions of volcanic gases.

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[1] Col. R. J. Strachey found oolitic fossils 18,400 feet high in the Himalaya.

Besides the parts of France above alluded to, there are other countries, as the north of Spain, the south of Sicily, the Tuscan territory of Italy, the lower Rhenish provinces, and Hungary, where spent volcanos may be seen, still preserving in many cases a conical form, and having craters and often lava-streams connected with them.

There are also other rocks in England, Scotland, Ireland, and almost every country in Europe, which we infer to be of igneous origin, although they do not form hills with cones and craters. Thus, for example, we feel assured that the rock of Staffa, and that of the Giant's Causeway, called basalt, is volcanic, because it agrees in its columnar structure and mineral composition with streams of lava which we know to have flowed from the craters of volcanos. We find also similar basaltic and other igneous rocks associated with beds of *tuff* in various parts of the British Isles and forming *dikes*, such as have been spoken of; and some of the strata through which these dikes cut are occasionally altered at the point of contact, as if they had been exposed to the intense heat of melted matter.

The absence of cones and craters, and long narrow streams of superficial lava, in England and many other countries, is principally to be attributed to the eruptions having been submarine, just as a considerable proportion of volcanos in our own times burst out beneath the sea. But this question must be enlarged upon more fully in the chapters on Igneous rocks, in which it will also be shown, that as different sedimentary formations, containing each their characteristic fossils, have been deposited at successive periods, so also volcanic sand and scoriæ have been thrown out, and lavas have flowed over the land or bed of the sea, at many different epochs, or have been injected into fissures; so that the igneous as well as the aqueous rocks may be classed as a chronological series of monuments, throwing light on a succession of events in the history of the earth.

Plutonic rocks (*Granite*, &c.).—We have now pointed out the existence of two distinct orders of mineral masses, the aqueous and the volcanic: but if we examine a large portion of a continent, especially if it contain within it a lofty mountain range, we rarely fail to discover two other classes of rocks, very distinct from either of those above alluded to, and which we can neither assimilate to deposits such as are now accumulated in lakes or seas, nor to those generated by ordinary volcanic action. The members of both these divisions of rocks agree in being highly crystalline and destitute of organic remains. The rocks of one division have been called plutonic, comprehending all the granites and certain porphyries, which are nearly allied in some of their characters to volcanic formations. The members of the other class are stratified and often slaty, and have been called by some the *crystalline schists*, in which group are included gneiss, micaceous-schist (or mica-slate), hornblende-schist, statuary marble, the finer kinds of roofing slate, and other rocks afterwards to be described.

As it is admitted that nothing strictly analogous to these crystalline productions can now be seen in the progress of formation on the earth's surface, it will naturally be asked, on what data we can find a place for them in a system of classification founded on the origin of rocks. I cannot, in reply to this question, pretend to give the student, in a few words, an intelligible account of the long chain of facts and reasonings from which geologists have been led to infer the nature of the rocks in question. The result, however, may be briefly stated. All the various kinds of granites which constitute the plutonic family, are supposed to be of igneous or aqueo-igneous origin, and to have been formed under great pressure, at a considerable depth in the earth, or sometimes, perhaps under a certain weight of incumbent ocean. Like the lava of volcanos, they have been melted, and afterwards cooled and crystallised, but with extreme slowness, and under conditions very different from those of bodies cooling in the open air. Hence they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases gives rise in ordinary lava.

Metamorphic, or stratified crystalline rocks.—The fourth and last great division of rocks are the crystalline strata and slates, or schists, called gneiss, mica-schist, clay-slate, chlorite-schist, marble, and the like, the origin of which is more doubtful than that of the other three classes. They contain no pebbles, or sand, or scoriæ, or angular pieces of imbedded stone, and no traces of organic bodies, and they are often as crystalline as granite, yet are divided into beds, corresponding in form and arrangement to those of sedimentary formations, and are therefore said to be stratified. The beds sometimes consist of an alternation of substances varying in colour, composition, and thickness, precisely as we see in stratified fossiliferous deposits. According to the Huttonian theory, which I adopt as the most probable, and which will be afterwards more fully explained, the materials of these strata were originally deposited from water in the usual form of sediment, but they were subsequently so altered by subterranean heat, as to assume a new texture. It is demonstrable, in some cases at least, that such a complete conversion has actually taken place, fossiliferous strata having exchanged an earthy for a highly crystalline texture for a distance of a quarter of a mile from their contact with granite. In some cases, dark limestones, replete with shells and corals, have been turned into white statuary marble, and hard clays, containing vegetable or other remains, into slates called mica-schist or hornblende-schist, every vestige of the organic bodies having been obliterated.

Although we are in a great degree ignorant of the precise nature of the influence exerted in these cases, yet it evidently bears some analogy to that which volcanic heat and gases are known to produce; and the action may be conveniently called plutonic, because it appears to have been developed in those regions where plutonic rocks are generated, and under similar circumstances of pressure and depth in the earth. Intensely heated water or steam permeating stratified masses under great pressure have no doubt played their part in producing the crystalline texture and other changes, and it is clear that the transforming influence has often pervaded entire mountain masses of strata.

In accordance with the hypothesis above alluded to, I proposed in the first edition of the Principles of Geology (1833), the term 'Metamorphic' for the altered strata, a term derived from μετά, meta, *trans*, and μορφή, morphe, *forma*.

Hence there are four great classes of rocks considered in reference to their origin,—the aqueous, the volcanic, the plutonic, and the metamorphic. In the course of this work it will be shown, that portions of each of these four distinct classes have originated at many successive periods. They have all been produced contemporaneously, and may even now be in the progress of formation on a large scale. It is not true, as was formerly supposed, that all granites, together with the crystalline or metamorphic strata, were first formed, and therefore entitled to be called 'primitive,' and that the aqueous and volcanic rocks were afterwards super-imposed, and should, therefore, rank as secondary in the order of time. This idea was adopted in the infancy of the science, when all formations, whether stratified or unstratified, earthy or crystalline, with or without fossils, were alike regarded as of aqueous origin. At that period it was naturally argued, that the foundation must be older than the superstructure; but it was afterwards discovered, that this opinion was by no means in every instance a legitimate deduction from facts; for the inferior parts of the earth's crust have often been modified, and even entirely changed, by the influence of volcanic and other subterranean causes, while super-imposed formations have not been in the slightest degree altered. In other words, the destroying and renovating processes have given birth to new rocks below, while those above, whether crystalline or fossiliferous, have remained in their ancient condition. Even in cities, such as Venice and Amsterdam, it cannot be laid down as universally true, that the upper parts of each edifice, whether of brick or marble, are more modern than the foundations on which they rest, for these often consist of wooden piles, which may have rotted and been replaced one after the other, without the least injury to the buildings above; meanwhile, these may have required scarcely any repair, and may have been constantly inhabited. So it is with the habitable surface of our globe, in its relation to large masses of rock immediately below: it may continue the same for ages, while subjacent materials, at a great depth, are passing from a solid to a fluid state, and then reconsolidating, so as to acquire a new texture.

As all the crystalline rocks may, in some respects, be viewed as belonging to one great family, whether they be stratified or unstratified, metamorphic or plutonic, it will often be convenient to speak of them by one common name. It being now ascertained, as above stated, that they are of very different ages, sometimes newer than the strata called secondary, the terms primitive and primary which were formerly used for the whole must be abandoned, as they would imply a manifest contradiction. It is indispensable, therefore, to find a new name, one which must not be of chronological import, and must express, on the one hand, some peculiarity equally attributable to granite and gneiss (to the plutonic, as well as the *altered* rocks), and, on the other, must have reference to characters in which those rocks differ, both from the volcanic and from the *unaltered* sedimentary strata. I proposed in the Principles of Geology (first edition, vol. iii.), the term 'hypogene' for this purpose, derived from ὑπό, *under*, and γίνομαι, *to be*, or *to be born*; a word implying the theory that granite, gneiss, and the other crystalline formations are alike *netherformed* rocks, or rocks which have not assumed their present form and structure at the surface. They occupy the lowest place in the order of superposition. Even in regions such as the Alps, where some masses of granite and gneiss can be shown to be of comparatively modern date, belonging, for example, to the period hereafter to be described as tertiary, they are still *underlying* rocks. They never repose on the volcanic or trappean formations nor on strata containing organic remains. They are *hypogene*, as 'being under' all the rest.

From what has now been said, the reader will understand that each of the four great classes of rocks may be studied under two distinct points of view; first, they may be studied simply as mineral masses deriving their origin from particular causes, and having a certain composition, form, and position in the earth's crust, or other characters both positive and negative, such as the presence or absence of organic remains. In the second place, the rocks of each class may be viewed as a grand chronological series of monuments, attesting a succession of events in the former history of the globe and its living inhabitants.

I shall accordingly proceed to treat of each family of rocks; first, in reference to those characters which are not chronological, and then in particular relation to the several periods when they were formed.

CHAPTER II.

AQUEOUS ROCKS—THEIR COMPOSITION AND FORMS OF STRATIFICATION.

Mineral composition of strata—Siliceous rocks—Argillaceous—Calcareous—Gypsum—Forms of stratification—Original horizontality—Thinning out—Diagonal arrangement—Ripple mark.

In pursuance of the arrangement explained in the last chapter, we shall begin by examining the aqueous or sedimentary rocks, which are for the most part distinctly stratified, and contain fossils. We may first study them with reference to their mineral composition, external appearance, position, mode of origin, organic contents, and other characters which belong to them as aqueous formations, independently of their age, and we may afterwards consider them chronologically or with reference to the successive geological periods when they originated.

I have already given an outline of the data which led to the belief that the stratified and fossiliferous rocks were originally deposited under water; but, before entering into a more detailed investigation, it will be desirable to say something of the ordinary materials of which such strata are composed. These may be said to belong principally to three divisions, the siliceous, the argillaceous, and the calcareous, which are formed respectively of flint, clay, and carbonate of lime. Of these, the siliceous are chiefly made up of sand or flinty grains; the argillaceous, or clayey, of a mixture of siliceous matter, with a certain proportion, about a fourth in weight, of aluminous earth; and, lastly, the calcareous rocks or limestones of carbonic acid and lime.

Siliceous and arenaceous rocks.—To speak first of the sandy division: beds of loose sand are frequently met with, of which the grains consist entirely of silex, which term comprehends all purely siliceous minerals, as quartz and common flint. Quartz is silex in its purest form. Flint usually contains some admixture of alumina and oxide of iron. The siliceous grains in sand are usually rounded, as if by the action of running water. Sandstone is an aggregate of such grains, which often cohere together without any visible cement, but more commonly are bound together by a slight quantity of siliceous or calcareous matter, or by oxide of iron or clay.

Pure siliceous rocks may be known by not effervescing when a drop of nitric, sulphuric or other acid is applied to them, or by the grains not being readily scratched or broken by ordinary pressure. In nature there is every intermediate gradation, from perfectly loose sand to the hardest sandstone. In *micaceous sandstones* mica is very abundant; and the thin silvery plates into which that mineral divides are often arranged in layers parallel to the planes of stratification, giving a slaty or laminated texture to the rock.

When sandstone is coarse-grained, it is usually called *grit* or, if the fragments are for the most part angular, a breccia. If the grains are rounded, and large enough to be called pebbles, it becomes a *conglomerate* or *pudding-stone*, which may consist of pieces of one or of many different kinds of rock. A conglomerate, therefore, is simply gravel bound together by a cement.

Argillaceous rocks.—Clay, strictly speaking, is a mixture of silex or flint with a large proportion, usually about one fourth, of alumina, or argil; but in common language, any earth which possesses sufficient ductility, when kneaded up with water, to be fashioned like paste by the hand, or by the potter's lathe, is called a *clay*; and such clays vary greatly in their composition, and are, in general, nothing more than mud derived from the decomposition or wearing down of rocks. The purest clay found in nature is porcelain clay, or kaolin, which results from the decomposition of a rock composed of felspar and quartz, and it is almost always mixed with quartz. The kaolin of China consists of 71·15 parts of silex, 15·86 of alumine, 1·92 of lime, and 6·73 of water;[1] but other porcelain clays differ materially, that of Cornwall being composed, according to Boase, of nearly equal parts of silica and alumine, with 1 per cent. of magnesia.[2] *Shale* has also the property, like clay, of becoming plastic in water: it is a more solid form of clay, or argillaceous matter, condensed by pressure. It always divides into laminæ more or less regular.

One general character of all argillaceous rocks is to give out a peculiar, earthy odour when breathed upon, which is a test of the presence of alumine, although it does not belong to pure alumine, but, apparently, to the combination of that substance with oxide of iron.[3]

Calcareous rocks.—This division comprehends those rocks which, like chalk, are composed chiefly of lime and carbonic acid. Shells and corals are also formed of the same elements, with the addition of animal matter. To obtain pure lime it is necessary to calcine these calcareous substances, that is to say, to expose them to heat of sufficient intensity to drive off the carbonic acid, and other volatile matter. White chalk is sometimes pure carbonate of lime; and this rock, although usually in a soft and earthy state, is occasionally sufficiently solid to be used for building, and even passes into a *compact* stone, or a stone of which the separate parts are so minute as not to be distinguishable from each other by the naked eye.

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[1] W. Phillips, Mineralogy, p. 33.

[2] Phil. Mag. vol. x. 1837.

[3] See W. Phillips's Mineralogy 'Alumine.'

Many limestones are made up entirely of minute fragments of shells and coral, or of calcareous sand cemented together. These last might be called 'calcareous sandstones;' but that term is more properly applied to a rock in which the grains are partly calcareous and partly siliceous, or to quartzose sandstones, having a cement of carbonate of lime.

The variety of limestone called *oolite* is composed of numerous small egg-like grains, resembling the roe of a fish, each of which has usually a small fragment of sand as a nucleus, around which concentric layers of calcareous matter have accumulated.

Any limestone which is sufficiently hard to take a fine polish is called *marble*. Many of these are fossiliferous; but statuary marble, which is also called saccharoid limestone, as having a texture resembling that of loaf-sugar, is devoid of fossils, and is in many cases a member of the metamorphic series.

Siliceous limestone is an intimate mixture of carbonate of lime and flint, and is harder in proportion as the flinty matter predominates.

The presence of carbonate of lime in a rock may be ascertained by applying to the surface a small drop of diluted sulphuric, nitric, or muriatic acids, or strong vinegar; for the lime, having a greater chemical affinity for any one of these acids than for the carbonic, unites immediately with them to form new compounds, thereby becoming a sulphate, nitrate, or muriate of lime. The carbonic acid, when thus liberated from its union with the lime, escapes in a gaseous form, and froths up or effervesces as it makes its way in small bubbles through the drop of liquid, This effervescence is brisk or feeble in proportion as the limestone is pure or impure, or, in other words, according to the quantity of foreign matter mixed with the carbonate of lime. Without the aid of this test, the most experienced eye cannot always detect the presence of carbonate of lime in rocks.

The above mentioned three classes of rocks, the siliceous, argillaceous, and calcareous, pass continually into each other, and rarely occur in a perfectly separate and pure form. Thus it is an exception to the general rule to meet with a limestone as pure as ordinary white chalk, or with clay as aluminous as that used in Cornwall for porcelain, or with sand so entirely composed of siliceous grains as the white sand of Alum Bay in the Isle of Wight, employed in the manufacture of glass, or sandstone so pure as the grit of Fontainebleau, used for pavement in France. More commonly we find sand and clay, or clay and marl, intermixed in the same mass. When the sand and clay are each in considerable quantity, the mixture is called *loam*. If there is much calcareous matter in clay it is called *marl*; but this term has unfortunately been used so vaguely, as often to be very ambiguous. It has been applied, for example, to substances in which there is no lime; as, to that red loam usually called red marl in certain parts of England. Agriculturists were in the habit of calling any soil a marl, which, like true marl, fell to pieces readily on exposure to the air. Hence arose the confusion of using this name for soils which, consisting of loam, were easily worked by the plough, though devoid of lime.

Marl slate bears the same relation to marl which shale bears to clay, being a calcareous shale. It is very abundant in some countries, as in the Swiss Alps. Argillaceous or marly limestone is also of common occurrence.

There are few other kinds of rock which enter so largely into the composition of sedimentary strata as to make it necessary to dwell here on their characters. I may, however, mention two others,—magnesian limestone or dolomite, and gypsum. *Magnesian limestone* is composed of carbonate of lime and carbonate of magnesia; the proportion of the latter amounting in some cases to nearly one half. It effervesces much more slowly and feebly with acids than common limestone. In England this rock is generally of a yellowish colour; but it varies greatly in mineralogical character, passing from an earthy state to a white compact stone of great hardness. *Dolomite*, so common in many parts of Germany and France, is also a variety of magnesian limestone, usually of a granular texture.

Gypsum is a rock composed of sulphuric acid, lime, and water. It is usually a soft whitish-yellow rock, with a texture resembling that of loaf-sugar, but sometimes it is entirely composed of lenticular crystals. It is insoluble in acids, and does not effervesce like chalk and dolomite, because it does not contain carbonic acid gas, or fixed air, the lime being already combined with sulphuric acid, for which it has a stronger affinity than for any other. Anhydrous gypsum is a rare variety, into which water does not enter as a component part. *Gypseous marl* is a mixture of gypsum and marl. *Alabaster* is a granular and compact variety of gypsum found in masses large enough to be used in sculpture and architecture. It is sometimes a pure snow-white substance, as that of Volterra in Tuscany, well known as being carved for works of art in Florence and Leghorn. It is a softer stone than marble, and more easily wrought.

Forms of stratification.—A series of strata sometimes consists of one of the above rocks, sometimes of two or more in alternating beds.

Thus, in the coal districts of England, for example, we often pass through several beds of sandstone, some of finer, others of coarser grain, some white, others of a dark colour, and below these, layers of shale and sandstone or beds of shale, divisible into leaf-like laminæ, and containing beautiful impressions of plants. Then again we meet with beds of pure and impure coal, alternating with shales and sandstones, and underneath the whole, perhaps, are calcareous strata, or beds of limestone, filled with corals and marine shells, each bed distinguishable from another by certain fossils, or by the abundance of particular species of shells or zoophytes.

This alternation of different kinds of rock produces the most distinct stratification ; and we often find beds of limestone and marl, conglomerate and sandstone, sand and clay, recurring again and again, in nearly regular order, throughout a series of many hundred strata. The causes which may produce these phenomena are various, and have been fully discussed in my treatise on the modern changes of the earth's surface.[1] It is there seen that rivers flowing into lakes and seas are charged with sediment, varying in quantity, composition, colour, and grain according to the seasons ; the waters are sometimes flooded and rapid, at other periods low and feeble ; different tributaries, also, draining peculiar countries and soils, and therefore charged with peculiar sediment, are swollen at distinct periods. It was also shown that the waves of the sea and currents undermine the cliffs during wintry storms, and sweep away the materials into the deep, after which a season of tranquillity succeeds, when nothing but the finest mud is spread by the movements of the ocean over the same submarine area.

It is not the object of the present work to give a description of these operations, repeated as they are, year after year, and century after century ; but I may suggest an explanation of the manner in which some micaceous sandstones have originated, namely, those in which we see innumerable thin layers of mica dividing layers of fine quartzose sand. I observed the same arrangement of materials in recent mud deposited in the estuary of La Roche St. Bernard in Brittany, at the mouth of the Loire. The surrounding rocks are of gneiss, which, by its waste, supplies *the mud: when this dries at low water, it is found to consist of brown laminated clay, divided by thin seams of mica.* The *separation of the mica in this case,* or in that of micaceous sandstones, may be thus understood. If we take a handful of quartzose sand, mixed with mica, and throw it into a clear running stream, we see the materials immediately sorted by the moving water, the grains of quartz falling almost directly to the bottom, while the plates of mica take a much longer time to sink through the water, and are carried farther down the stream. At the first instant the water is turbid, but almost immediately the flat surfaces of the plates of mica are seen all alone reflecting a silvery light, as they descend slowly, to form a distinct micaceous lamina. The mica is the heavier mineral of the two; but it remains a longer time suspended in the fluid, owing to its greater extent of surface. It is easy, therefore, to perceive that where such mud is acted upon by a river or tidal current, the thin plates of mica will be carried farther, and not deposited in the same places as the grains of quartz; and since the force and velocity of the stream varies from time to time, layers of mica or of sand will be thrown down successively on the same area.

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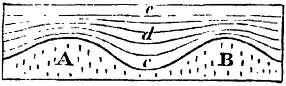
[1] Consult Index to Principles of Geology, 'Stratification,' 'Currents,' 'Deltas,' 'Water,' &c.

Original horizontality.—It is said generally that the upper and under surfaces of strata, or the 'planes of stratification,' are parallel. Although this is not strictly true, they make an approach to parallelism, for the same reason that sediment is usually deposited at first in nearly horizontal layers. Such an arrangement can by no means be attributed to an original evenness or horizontality in the bed of the sea: for it is ascertained that in those places where no matter has been recently deposited, the bottom of the ocean is often as uneven as that of the dry land, having in like manner its hills, valleys, and ravines. Yet if the sea should go down, or be removed from near the mouth of a large river where a delta has been forming, we should see extensive plains of mud and sand laid dry, which, to the eye, would appear perfectly level, although, in reality, they would slope gently from the land towards the sea.

This tendency in newly-formed strata to assume a horizontal position arises principally from the motion of the water, which forces along particles of sand or mud at the bottom, and causes them to settle in hollows or depressions where they are less exposed to the force of a current than when they are resting on elevated points. The velocity of the current and the motion of the superficial waves diminish from the surface downwards, and are least in those depressions where the water is deepest.

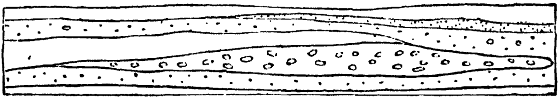
A good illustration of the principle here alluded to may be sometimes seen in the neighbourhood of a volcano, when a section, whether natural or artificial, has laid open to view a succession of various-coloured layers of sand and ashes, which have fallen in showers upon uneven ground. Thus let A B (fig. 1) be two ridges, with an intervening valley. These original inequalities of the surface have been gradually effaced by beds of sand and ashes, *c*, *d*, *e*, the surface at *e* being quite level. It will be seen that, although the materials of the first layers have accommodated themselves in a great degree to the shape of the ground A B, yet each bed is thickest at the bottom. At first a great many particles would be carried by their own gravity down the steep sides of A and B, and others would afterwards be blown by the wind as they fell off the ridges, and would settle in the hollow, which would thus become more and more effaced as the strata accumulated from *c* to *e*. Now, water in motion can exert this levelling power on similar materials more easily than air, for almost all stones lose in water more than a third of the weight which they have in air, the specific gravity of rocks being in general as 2½ when compared to that of water, which is estimated at 1. But the buoyancy of sand or mud would be still greater in the sea, as the density of salt water exceeds that of fresh.

Fig. 1.



Yet, however uniform and horizontal may be the surface of new deposits in general, there are still many disturbing causes, such as eddies in the water, and currents moving first in one and then in another direction, which frequently cause irregularities. We may sometimes follow a bed of limestone, shale, or sandstone, for a distance of many hundred yards continuously; but we generally find at length that each individual stratum thins out, and allows the beds which were previously above and below it to meet. If the materials are coarse, as in grits and conglomerates, the same beds can rarely be traced many yards

Fig. 2.

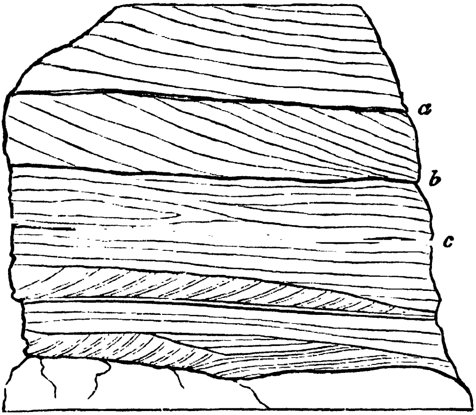


Section of strata of sandstone, grit, and conglomerate.

without varying in size, and often rapidly thinning out and coming to an end. (See fig. 2.)

Diagonal or cross stratification.—There is also another phenomenon of frequent occurrence. We find a series of larger strata, each of which is composed of a number of minor layers placed obliquely to the general planes of stratification. To this diagonal arrangement the name of 'false or cross bedding' has been given. Thus in the annexed section (fig. 3) we see seven or eight large beds of loose sand, yellow and brown, and the lines, *a*, *b*, *c*, mark some of the principal planes of stratification, which are nearly horizontal. But the greater part of the subordinate laminæ do not conform to these planes, but have often a steep slope, the inclination being sometimes towards opposite points of the compass. When the sand is loose and incoherent, as in the case here represented, the deviation from parallelism of the slanting laminæ cannot possibly be accounted for by any re-arrangement of the particles acquired during the consolidation of the rock. In what manner, then, can such irregularities be due to original deposition? We must suppose that at the bottom of the sea, as well as in the beds of rivers, the motions of waves, currents, and eddies often cause mud, sand, and gravel to be thrown down in heaps on particular spots instead of being spread out uniformly over a wide area. Sometimes, when banks are thus formed, currents may cut passages through

Fig. 3.



Section of sand at Sandy Hill, near Biggleswade, Bedfordshire. Height 20 ft. (Green-sand formation.)

them, just as a river forms its bed. Suppose the bank A (fig. 4) to be thus formed with a steep sloping side, and the water being in a tranquil state, the layer of sediment No. 1 is thrown down upon it, conforming nearly to its surface. Afterwards the other layers, 2, 3, 4, may be deposited in succession, so that the bank B C D is formed. If the current then increases in velocity, it may cut away the upper portion of this mass down to the dotted line *e*, and deposit the materials thus removed farther on, so as to form the layers 5, 6, 7, 8. We have now the bank B C D E (fig. 5), of which the surface is almost level, and on which the nearly horizontal layers, 9, 10, 11, may then accumulate. It was shown in fig. 3 that the diagonal layers of successive strata may sometimes have an opposite slope. This is well seen in some cliffs of loose sand on the Suffolk coast. A portion of one of these is represented in fig. 6, where the layers, of which there are about six in the thickness of an inch, are composed of quartzose grains. This arrangement may have been due to the altered direction of the tides and currents in the same place.

Fig. 4.

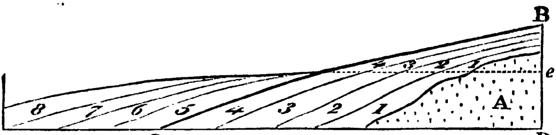


Fig. 5.

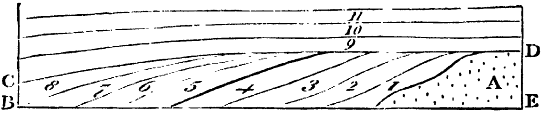
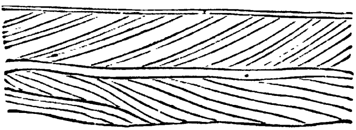


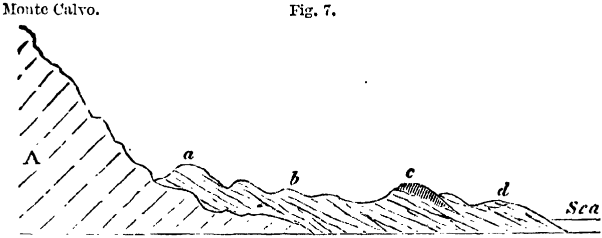
Fig. 6.



Cliff between Mismer and Dunwich.

The description above given of the slanting position of the minor layers constituting a single stratum is in certain cases applicable on a much grander scale to masses several hundred feet thick, and many miles in extent. A fine example may be seen at the base of the Maritime Alps near Nice. The mountains here terminate abruptly in the sea, so that a depth of one hundred fathoms is often found within a stone's throw of the beach, and sometimes a *depth of 3,000 feet within half a mile.* But at certain points, strata of sand, marl, or conglomerate, intervene between the shore and the mountains, as in the section (fig. 7), where a vast succession of slanting beds of gravel and sand may be traced from the sea to Monte Calvo, a distance of no less than 9 miles in a straight line. The dip of these beds is remarkably uniform, being always southward or towards the Mediterranean, at an angle of about 25°. They are exposed to view in nearly vertical precipices, varying from 200 to 600 feet in height, which bound the valley through which the river Magnan flows.

Fig. 7.



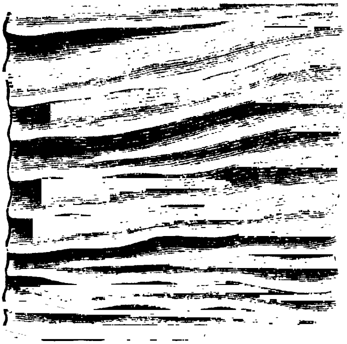
Section from Monte Calvo to the sea by the valley of Magnan, near Nice.

A. Dolomite and sandstone. (Green sand formation ?)
a, *b*, *d*. Beds of gravel and sand.
c. Fine marl and sand of Ste. Madeleine, with marine (Pliocene) shells.

Although, in a general view, the strata appear to be parallel and uniform, they are nevertheless found, when examined closely, to be wedge-shaped, and to thin out when followed for a few hundred feet or yards, so that we may suppose them to have been thrown down originally upon the side of a steep bank where a river or alpine torrent discharged itself into a deep and tranquil sea, and formed a delta, which advanced gradually from the base of Monte Calvo to a distance of 9 miles from the original shore. If subsequently this part of the Alps and bed of the sea were raised 700 feet, the delta may have emerged, a deep channel may then have been cut through it by the river, and the coast may at the same time have acquired its present configuration.

It is well known that the torrents and streams, which now descend from the alpine declivities to the shore, bring down annually, when the snow melts, vast quantities of shingle and sand, and then, as they subside, fine mud, while in summer they are nearly or entirely dry; so that it may be safely assumed, that deposits like those of the valley of the Magnan, consisting of coarse gravel alternating with fine sediment, are still in progress at many points, as, for instance, at the mouth of the Var. They must advance upon the Mediterranean in the form of great shoals terminating in a steep talus ; such being the original mode of accumulation of all coarse materials conveyed into deep water, especially where they are composed in great part of pebbles, which cannot be transported to indefinite distances by currents of moderate velocity. By inattention to facts and inferences of this kind, a very exaggerated estimate has sometimes been made of the supposed depth of the ancient ocean. There can be no doubt, for example, that the strata *a*, fig. 7, or those nearest to Monte Calvo, are older than those indicated by *b*, and these again were formed before *c* ; but the vertical depth of gravel and sand in any one place cannot be proved to amount even to 1,000 feet, although it may perhaps be much greater, yet probably never exceeding at any point 3,000 or 4,000 feet. But were we to assume that all the strata were once horizontal, and that their present dip or inclination was due to subsequent movements, we should then be forced to conclude, that a sea several miles deep had been filled up with alternate layers of mud and pebbles thrown down one upon another.

Fig. 8.



Slab of ripple-marked (New Red) sandstone from Cheshire.

In the locality now under consideration, situated a few miles to the west of Nice, there are many geological data, the details of which cannot be given in this place, all leading to the opinion, that when the deposit of the Magnan was formed, the shape and outline of the alpine declivities and the shore greatly resembled what we now behold at many points in the neighbourhood. That the beds, *a*, *b*, *c*, *d*, are of comparatively modern date is proved by this fact, that in seams of loamy marl intervening between the pebbly beds are fossil shells, half of which belong to species now living in the Mediterranean.

Ripple mark.—The ripple mark, so common on the surface of sandstones of all ages (see fig. 8), and which is so often seen on the sea-shore at low tide, seems to originate in the drifting of materials along the bottom of the water, in a manner very similar to that which may explain the inclined layers above described. This ripple is not entirely confined to the beach between high and low water mark, but is also produced on sands which are constantly covered by water. Similar undulating ridges and furrows may also be sometimes seen on the surface of drift snow and blown sand.

The ripple mark is usually an indication of a sea-beach, or of water from 6 to 10 feet deep, for the agitation caused by waves even during storms extends to a very slight depth. To this rule, however, there are some exceptions, and recent ripple marks have been observed at the depth of 60 or 70 feet. It has also been ascertained that currents or large bodies of water in motion may disturb mud and sand at the depth of 300 or even 450 feet.[1] Beach ripple, however, may usually be distinguished from current ripple by frequent changes in its direction. In a slab of sandstone, not more than an inch thick, the furrows or ridges of an ancient ripple may often be seen in several successive laminæ to run towards different points of the compass.

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[1] Darwin, Volc. Islands, p. 134.

CHAPTER III.

ARRANGEMENT OF FOSSILS IN STRATA—FRESHWATER AND MARINE.

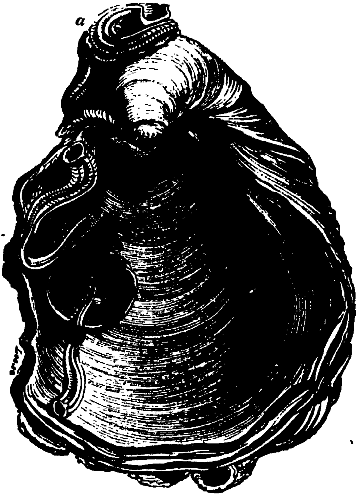
Successive deposition indicated by fossils—Limestones formed of corals and shells—Proofs of gradual increase of strata derived from fossils—Serpula attached to spatangus—Wood bored by teredina—Tripoli formed of infusoria—Chalk derived principally from organic bodies—Distinction of freshwater from marine formations—Genera of freshwater and land shells—Rules for recognising marine testacea—Gyrogonite and chara—Freshwater fishes—Alternation of marine and freshwater deposits—Lym-Fiord.

Having in the last chapter considered the forms of stratification so far as they are determined by the arrangement of inorganic matter, we may now turn our attention to the manner in which organic remains are distributed through stratified deposits. We should often be unable to detect any signs of stratification or of successive deposition, if particular kinds of fossils did not occur here and there at certain depths of the mass. At one level, for example, univalve shells of some one or more species predominate ; at another, bivalve shells ; and at a third, corals ; while in some formations we find layers of vegetable matter, commonly derived from land plants, separating strata.

It may appear inconceivable to a beginner how mountains, several thousand feet thick, can have become full of fossils from top to bottom ; but the difficulty is removed, when he reflects on the origin of stratification, as explained in the last chapter, and allows sufficient time for the accumulation of sediment. He must never lose sight of the fact that, during the process of deposition, each separate layer was once the uppermost, and immediately in contact with the water in which aquatic animals lived. Each stratum in fact, however far it may now lie beneath the surface, was once in the state of shingle, or loose sand or soft mud at the bottom of the sea, in which shells and other bodies easily became enveloped.

Rate of deposition indicated by fossils.—By attending to the nature of these remains, we are often enabled to determine whether the deposition was slow or rapid, whether it took place in a deep or shallow sea, near the shore or far from land, and whether the water was salt, brackish, or fresh. Some limestones consist almost exclusively of corals, and in many cases *it is* evident that the present position of each fossil zoophyte has been determined by the manner in which it grew originally. The axis of the coral, for example, if its natural growth is erect, still remains at right angles to the plane of stratification. If the stratum be now horizontal, the round spherical heads of certain species continue uppermost, and their points of attachment are directed downwards. This arrangement is sometimes repeated throughout a great succession of strata. From what we know of the growth of similar zoophytes in modern reefs, we infer that the rate of increase was extremely slow, and some of the fossils must have flourished for ages like forest trees, before they attained so large a size. During these ages, the water must have been clear and transparent, for such corals cannot live in turbid water.

Fig. 9.



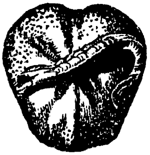
Fossil *Gryphæa*, covered both on the outside and inside with fossil serpulæ.

In like manner, when we see thousands of full-grown shells dispersed everywhere throughout a long series of strata, we cannot doubt that time was required for the multiplication of successive generations; and the evidence of slow accumulation is rendered more striking from the proofs, so often discovered, of fossil bodies having lain for a time on the floor of the ocean after death before they were imbedded in sediment. Nothing, for example, is more common than to see fossil oysters in clay, with serpulæ, or barnacles (acorn-shells), or corals, and other creatures attached to the inside of the valves, so that the mollusk was certainly not buried in argillaceous mud the moment it died. There must have been an interval during which it was still surrounded with clear water, when the creatures whose remains now adhere to it, grew from an embryonic to a mature state. Attached shells which are merely external, like some of the serpulæ (*a*) in fig. 9, may often have grown upon an oyster or other shell while the animal within was still living;

but if they are found on the inside, it could only happen after the death of the inhabitant of the shell which affords the support. Thus, in fig. 9, it will be seen that two serpulæ have grown on the interior, one of them exactly on the place where the adductor muscle of the *Gryphæa* (a kind of oyster) was fixed.

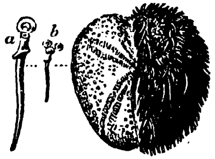
Some fossil shells, even if simply attached to the *outside* of others, bear full testimony to the conclusion above alluded to, namely, that an interval elapsed between the death of the creature to whose shell they adhere, and the burial of the same in mud or sand. The sea-urchins or *Echini*, so abundant in white chalk, afford a good illustration. It is well known that these animals, when living, are invariably covered with spines supported by rows of tubercles. These last are only seen after the death of the sea-urchin, when the spines have dropped off. In fig. 11 a living species of *Spatangus*, common on our coast, is represented with one half of its shell stripped of the spines. In fig. 10 a fossil of a similar and allied genus from the white chalk of England shows the naked surface which the individuals of this family exhibited when denuded of their bristles. The full-grown *Serpula*, therefore, which now adheres externally, could not have begun to grow till the *Micraster* had died, and the spines became detached.

Fig. 10.



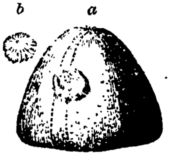
Serpula attached to a fossil *Micraster* from the chalk.

Fig. 11.



Recent *Spatangus* with the spines removed from one side.
b. Spine and tubercles, nat. size
a. The same magnified.

Fig. 12.

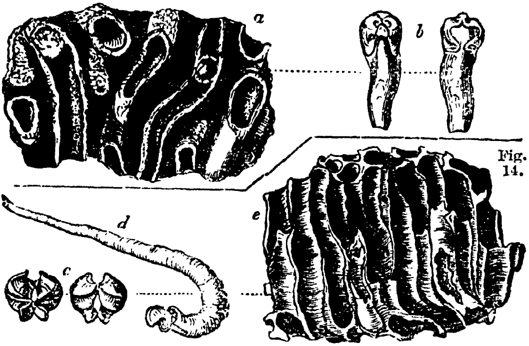


a. *Ananchytes* from the chalk with lower valve of *Crania* attached.
b. Upper valve of *Crania* detached.

Now the series of events here attested by a single fossil may be carried a step farther. Thus, for example, we often meet with a sea-urchin (*Ananchytes*) in the chalk (see fig. 12), which has fixed to it the lower valve of a *Crania*, a genus of bivalve mollusca. The upper valve (*b*, fig. 12), is almost invariably wanting, though occasionally found in a perfect state of preservation in white chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines which were carried away. Then the young *Crania* adhered to the bared shell, grew and perished in its turn; after which the upper valve was separated from the lower before the *Ananchytes* became enveloped in chalky mud.

It may be well to mention one more illustration of the manner in which single fossils may sometimes throw light on a former state of things, both in the bed of the ocean and on some adjoining land. We meet with many fragments of wood bored by ship-worms, at various depths in the clay on which London is built. Entire branches and stems of trees, several feet in length, are sometimes found drilled all over by the holes of these borers, the tubes and shells of the mollusk still remaining in the cylindrical hollows. In fig. 14, *e*, a representation is given of a piece of recent wood pierced by the *Teredo navalis*, or common ship-worm, which destroys wooden piles and ships. When the cylindrical tube *d* has been extracted from the wood, the valves are seen at the larger or anterior extremity, as shown at *c*. In like manner, a piece of fossil wood (*a*, fig. 13) has been perforated by a kindred but distinct genus, the *Teredina* of Lamarck. The calcareous tube of this mollusk was united and as it were soldered on to the valves of the shell (*b*), which

Fig. 13.



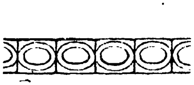
Fossil and recent wood drilled by perforating Mollusca.

Fig. 13. *a*. Fossil wood from London clay, bored by *Teredina*.
b. Shell and tube of *Teredina personata*, the right-hand figure the ventral, the left the dorsal view.
Fig. 14. *e*. Recent wood bored by *Teredo*.
d. Shell and tube of *Teredo navalis*, from the same.
c. Anterior and posterior view of the valves of same detached from the tube.

therefore cannot be detached from the tube, like the valves of the recent *Teredo*. The wood in this fossil specimen is now converted into a stony mass, a mixture of clay and lime ; but it must once have been buoyant and floating in the sea, when the *Teredinæ* lived upon, and perforated it. Again, before the infant colony settled upon the drift wood, part of a tree must have been floated down to the sea by a river, uprooted, perhaps, by a flood, or torn off and cast into the waves by the wind : and thus our thoughts are carried back to a prior period, when the tree grew for years on dry land, enjoying a fit soil and climate.

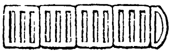
Strata of organic origin.—It has been already remarked that there are rocks in the interior of continents, at various depths in the earth, and at great heights above the sea, almost entirely made up of the remains of zoophytes and testacea. Such masses may be compared to modern oyster-beds and coral-reefs ; and, like them, the rate of increase must have been extremely gradual. But there are a variety of stone deposits in the earth's crust, now proved to have been derived from plants and animals of which the organic origin was not suspected until of late years, even by naturalists. Great surprise was therefore created some years since by the discovery of Professor Ehrenberg, of Berlin, that a certain kind of siliceous stone, called tripoli, was entirely composed of millions of the remains of organic beings, which were formerly referred to microscopic Infusoria, but which are now admitted to be plants. They abound in rivulets, lakes, and ponds in England and other countries, and are termed Diatomaceæ by those naturalists who believe in their vegetable origin. The subject alluded to has long been well known in the arts, under the name of Infusorial Earth or Mountain Meal, and is used in the form of powder for polishing stones and metals. It has been procured, among other places, from the mud of a lake at Dolgelly in North Wales, and from Bilin, in Bohemia, in which latter place a single stratum, extending over a wide area, is no less than 14 feet thick. This stone, when examined with a powerful microscope, is found o

Fig. 15.



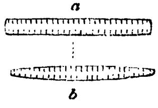
Gaillonella ferruginea, Ehb.

Fig. 16.



Gaillonella distans, Ehb.

Fig. 17.



Bacillaria paradoxa. *a.* Front view. *b.* Side view.

consist of the siliceous plates of the above figured Diatomaceæ, united together without any visible cement. It is difficult to convey an idea of their extreme minuteness; but Ehrenberg estimates that in the Bilin tripoli there are 41,000 millions of individuals of the *Gaillonella distans* (see fig. 16) in every cubic inch (which weighs about 220 grains), or about 187 millions in a single grain. At every stroke, therefore, that we make with this polishing powder, several millions, perhaps tens of millions, of perfect fossils are crushed to atoms.

A well-known substance, called bog-iron ore, often met with in peat-mosses, has been shown by Ehrenberg to consist of innumerable articulated threads, of a yellow ochre colour, composed of silica, argillaceous matter, and peroxide of iron. These threads are the cases of a minute microscopic body, called *Gaillonella ferruginea* (fig. 15) associated with the siliceous plates of other freshwater algæ. Layers of this iron ore occurring in Scotch peat bogs are often called 'the pan,' and are sometimes of economical value.

It is clear that much time must have been required for the accumulation of strata to which countless generations of Diatomaceæ have contributed their remains; and these discoveries lead us naturally to suspect that other deposits, of which the materials have been supposed to be inorganic, may in reality be composed chiefly of microscopic organic bodies. That this is the case with the white chalk, has often been imagined, and is now proved to be the fact. It has, moreover, been lately discovered that the chambers into which these Foraminifera are divided are actually often filled with thousands of well-preserved organic bodies, which abound in every minute grain of chalk, and are especially apparent in the white coating of flints, often accompanied by innumerable needle-shaped spiculæ of sponges (see Chap. XVII.).

> The dust we tread upon was once alive!—BYRON.

How faint an idea does this exclamation of the poet convey of the real wonders of nature! for here we discover proofs that the calcareous and siliceous dust of which whole hills are composed has not only been once alive, but almost every particle, albeit invisible to the naked eye, still retains the organic structure which, at periods of time incalculably remote, was impressed upon it by the powers of life.

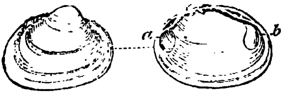
Freshwater and marine fossils.—Strata, whether deposited in salt or fresh water, have the same forms; but the imbedded fossils are very different in the two cases, because the aquatic animals which frequent lakes and rivers are distinct from those inhabiting the sea. In the northern part of the Isle of Wight formations of marl and limestone, more than 50 feet thick, occur, in which the shells are of extinct species. Yet we recognise their freshwater origin, because they are of the same genera as those now abounding in ponds, lakes, and rivers, either in our own country or in warmer latitudes.

In many parts of France, in Auvergne, for example, strata occur of limestone, marl, and sandstone hundreds of feet thick, which contain exclusively freshwater and land shells, together with the remains of terrestrial quadrupeds. The number of land shells scattered through some of these freshwater deposits is exceedingly great; and there are districts in Germany where the rocks scarcely contain any other fossils except snail-shells (*helices*); as, for instance, the limestone on the left bank of the Rhine, between Mayence and Worms, at Oppenheim, Findheim, Budenheim, and other places. In order to account for this phenomenon, the geologist has only to examine the small deltas of torrents which enter the Swiss lakes when the waters are low, such as the newly-formed plain where the Kander enters the Lake of Thun. He there sees sand and mud strewn over with innumerable dead land shells, which have been brought down from the valleys in the Alps in the preceding spring, during the melting of the snows. Again, if we search the sands on the borders of the Rhine, in the lower part of its course, we find countless land shells mixed with others of species belonging to lakes, stagnant pools, and marshes. These individuals have been washed away from the alluvial plains of the great river and its tributaries, some from mountainous regions, others from the low country.

Although freshwater formations are often of great thickness, yet they are usually very limited in area when compared to marine deposits, just as lakes and estuaries are of small dimensions in comparison with seas.

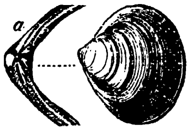
The absence of many fossil forms usually met with in marine strata, affords a useful negative indication of the freshwater origin of a formation. For example, there are no sea-urchins, no corals, no chambered shells, such as the nautilus, nor microscopic Foraminifera in lacustrine or fluviatile deposits. In distinguishing the latter from formations accumulated in the sea, we are chiefly guided by the forms of the mollusca. In a freshwater deposit, the number of individual shells is often as great as in a marine stratum, if not greater; but there is a smaller variety of species and genera. This might be anticipated from the fact that the genera and species of recent freshwater and land shells are few when contrasted with the marine. Thus, the genera of true mollusca according to Woodward's system, excluding those altogether extinct and those without shells, amount to 446 in number, of which the terrestrial and freshwater genera scarcely form more than a fifth.[1]

Fig. 18.



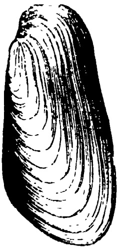
Cyclas (*Sphærium*) *corneus*, Sow.; living and fossil.

Fig. 19.



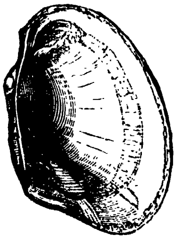
Cyrena (*Corbicella*) *fluminalis*, Möll.; fossil. Grays, Essex, and living in the Nile.

Fig. 20.



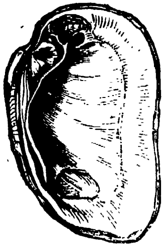
Anodonta Cordierii; D'Orb. Paris.

Fig. 21.



Anodonta latimarginata; recent. Bahia.

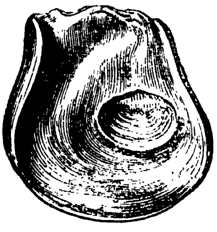
Fig. 22.



Unio littoralis; Lam.; recent. Auvergne.

Almost all bivalve shells, or those of acephalous mollusca, are marine, about sixteen only out of 140 genera being freshwater. Among these last, the four most common forms, both recent and fossil, are *Cyclas* (*Sphærium*), *Cyrena*, *Unio*, and *Anodonta* (see figures); the two first and two last of which are so nearly allied as to pass into each other.

Fig. 23.



Gryphæa incurva, Sow.; (*G. arcuata*, Lam.) upper valve. Lias.

Lamarck divided the bivalve mollusca into the *Dimyary*, or those having two large muscular impressions in each valve, as *a b* in the Cyclas, fig. 18, and Unio, fig. 22, and the *Monomyary*, such as the oyster and scallop, in which there is only one of these impressions, as seen in fig. 23. Now, as none of these last, or the unimuscular bivalves, are freshwater,[1] we may at once presume a deposit containing any of them to be marine.

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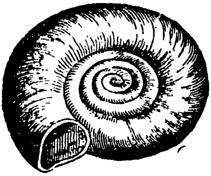
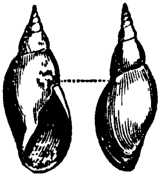
[1] See Woodward's Manual of Mollusca, 1856.

Fig. 24.



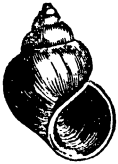
Planorbis euomphalus, Sow.; fossil. Isle of Wight.

Fig. 25.



Limnæa longiscata, Brong.; fossil. Isle of Wight.

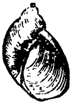
Fig. 26.



Paludina vivipara, Brand; living and fossil.

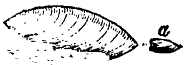
The univalve shells most characteristic of freshwater deposits are, *Planorbis*, *Limnæa*, and *Paludina*. (See figures.) But to these are occasionally added *Physa*, *Succinea*, *Ancylus*, *Valvata*, *Melanopsis*, *Melania*, *Potamides*, and *Neritina* (see figures), the four last being usually found in estuaries.

Fig. 27.



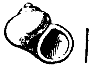
Succinea amphibia, Drap. (S. Putris, L.); fossil. Loess, Rhine.

Fig. 28.



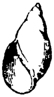
Ancylus velletia (A. elegans), Sow.; fossil. Isle of Wight.

Fig. 29.



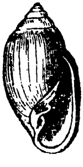
Valvata piscinalis, Müll.; fossil. Grays, Essex.

Fig. 30.



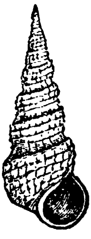
Physa hypnorum, Linn.; recent. Isle of Wight.

Fig. 31.



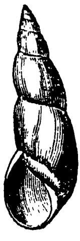
Auricula; recent. Ava.

Fig. 32.



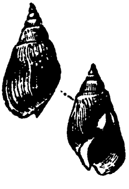
Cerithium funatum, Forbes. Isle of Wight.

Fig. 33.



Physa columnaris, Desh. Paris basin.

Fig. 34.



Melanopsis buccinoidea Ferr.; recent. Asia.

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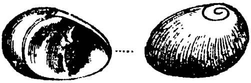
[1] The freshwater Mulleria, which, when young, has two muscular impressions, has only one in the adult state, thus forming a single exception to the rule.

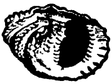
Some naturalists include *Neritina* (fig. 35) and the marine *Nerita* (fig. 36) in the same genus, it being scarcely possible to distinguish the two by good generic characters. But, as a general rule, the fluviatile species are smaller, smoother, and more globular than the marine; and they have never, like the *Neritæ*, the inner margin of the outer lip toothed or crenulated. (See fig. 36.)

Fig. 35.



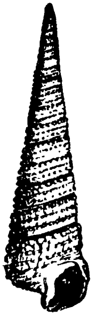
Neritina globulus, Def. Paris basin.

Fig. 36.



Nerita granulosa Desh. Paris basin.

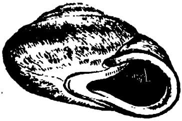
Fig. 37.



Potamides cinctus, Sow. Paris basin.

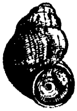
The Potamides inhabit the mouths of rivers in warm latitudes, and are distinguishable from the marine Cerithia by their orbicular and multispiral opercula. The genus Auricula (fig. 31) is amphibious, frequenting swamps and marshes within the influence of the tide.

Fig. 38.



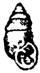
Helix Turonensis, Desh.; Faluns, Touraine.

Fig. 39.

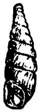


Cyclostoma elegans, Müll.; Loess.

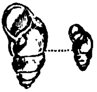
Fig. 40.



Pupa tridens Drap.; Loess.



Clausilia bidens, Drap.; Loess.

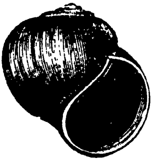


Bulimus l Müll.; Loess, Rhine.

The terrestrial shells are all univalves. The most important genera among these, both in a recent and fossil state, are *Helix* (fig. 38), *Cyclostoma* (fig. 39), *Pupa* (fig. 40), *Clausilia* (fig. 41), *Bulimus* (fig. 42), *Glandina*, and *Achatina*.

Ampullaria (fig. 43) is another genus of shells, inhabiting rivers and ponds in hot countries. Many fossil species formerly referred to this genus, and which have been met with chiefly in marine formations, are now considered by conchologists to belong to *Natica* and other marine genera.

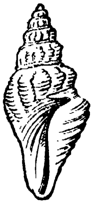
Fig. 43.



Ampullaria glauca, from the Jumna.

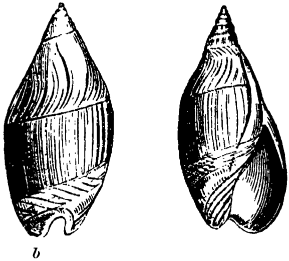
All univalve shells of land and freshwater species, with the exception of *Melanopsis* (fig. 34), and *Achatina*, which has a slight indentation, have entire mouths; and this circumstance may often serve as a convenient rule for distinguishing freshwater from marine strata; since, if any univalves occur of which the mouths are not entire, we may presume that the formation is marine. The aperture is said to be entire in such shells as the freshwater *Ampullaria* and the land shells (figs. 38–42), when its outline is not interrupted by an indentation or notch, such as that seen at *b* in *Ancillaria* (fig. 45); or is not prolonged into a canal, as that seen at *a* in *Pleurotoma* (fig. 44).

Fig. 44.



Pleurotoma exorta, Brand.
Upper and Middle Eocene.
Barton and Bracklesham.

Fig. 45.



Ancillaria subulata, Sow.
Barton clay. Eocene.

The mouths of a large proportion of the marine univalves have these notches or canals, and almost all the species are carnivorous; whereas nearly all testacea having entire mouths, are plant-eaters; whether the species be marine, freshwater, or terrestrial.

There is, however, one genus which affords an occasional exception to one of the above rules. The *Potamides* (fig. 37), a subgenus of Cerithium, although provided with a short canal, comprises some species which inhabit salt, others brackish, and others fresh water, and they are said to be all plant-eaters.

Among the fossils very common in freshwater deposits are the shells of *Cypris*, a minute bivalve crustaceous animal.[1] Many minute living species of this genus swarm in lakes and stagnant pools in Great Britain; but their shells are not, if considered separately, conclusive as to the freshwater origin of a deposit, because the majority of species in another kindred genus of the same order, the *Cytherina* of Lamarck, inhabit salt water; and, although the animal differs slightly, the shell is scarcely distinguishable from that of the *Cypris*.

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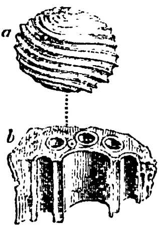
[1] For figures of fossil species of Purbeck, see below, Ch. XIX.

Freshwater fossil plants.—The seed-vessels and stems of *Chara*, a genus of aquatic plants, are very frequent in freshwater strata. These seed-vessels were called, before their true nature was known, gyrogonites, and were supposed to be foraminiferous shells. (See fig. 46, *a*.)

The Charæ inhabit the bottom of lakes and ponds, and flourish mostly where the water is charged with carbonate of lime.

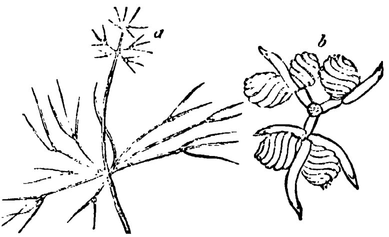
Fig. 46.



Chara medicaginula; fossil. Upper Eocene, Isle of Wight.

a. Seed-vessel magnified 20 diameters.
b. Stem, magnified.

Fig. 47.



Chara elastica; recent. Italy.

a. Sessile seed-vessel between the divisions of the leaves of the female plant.
b. Magnified transverse section of a branch, with five seed-vessels, seen from below upwards.

Their seed-vessels are covered with a very tough integument, capable of resisting decomposition; to which circumstance we may attribute their abundance in a fossil state. The annexed figure (fig. 47) represents a branch of one of many new species found by Professor Amici in the lakes of Northern Italy. The seed-vessel in this plant is more globular than in the British *Charæ*, and therefore more nearly resembles in form the extinct fossil species found in England, France, and other countries. The stems, as well as the seed-vessels, of these plants occur both in modern shell marl and in ancient freshwater formations. They are generally composed of a large central tube surrounded by smaller ones; the whole stem being divided at certain intervals by transverse partitions or joints. (See *b*, fig. 46.)

It is not uncommon to meet with layers of vegetable matter, impressions of leaves, and branches of trees, in strata containing freshwater shells; and we also find occasionally the teeth and bones of land quadrupeds, of species now unknown. The manner in which such remains are occasionally carried by rivers into lakes, especially during floods, has been fully treated of in the 'Principles of Geology.'

Freshwater and marine fish.—The remains of fish are occathickness resting on freshwater strata. When we find, as in the south-east of England (Chap. XVIII.) a great series of freshwater beds, 1,000 feet thick, resting upon marine formations and again covered by other rocks, such as the cretaceous, more than 1,000 feet thick, and of deep-sea origin, we shall find it necessary to seek for a different explanation of the phenomena.

CHAPTER IV.

CONSOLIDATION OF STRATA AND PETRIFACTION OF FOSSILS.

Chemical and mechanical deposits—Cementing together of particles—Hardening by exposure to air—Concretionary nodules—Consolidating effects of pressure—Mineralisation of organic remains—Impressions and casts, how formed—Fossil wood—Göppert's experiments—Precipitation of stony matter most rapid where putrefaction is going on—Sources of lime and silex in solution.

HAVING spoken in the preceding chapters of the characters of sedimentary formations, both as dependent on the deposition of inorganic matter and the distribution of fossils, I may next treat of the consolidation of stratified rocks, and the petrifaction of imbedded organic remains.

Chemical and mechanical deposits.—A distinction has been made by geologists between deposits of a mechanical, and those of a chemical, origin. By the name mechanical are designated beds of mud, sand, or pebbles produced by the action of running water, also accumulations of stones and scoriæ thrown out by a volcano, which have fallen into their present place by the force of gravitation. But the matter which forms a chemical deposit has not been mechanically suspended in water, but in a state of solution until separated by chemical action. In this manner carbonate of lime is occasionally precipitated upon the bottom of lakes in a solid form, as may be well seen in many parts of Italy, where mineral springs abound, and where the calcareous stone, called travertin, is deposited. In these springs the lime is usually held in solution by an excess of carbonic acid, or by heat if it be a hot spring, until the water, on issuing from the earth, cools or loses part of its acid. The calcareous matter then falls down in a solid state, encrusting shells, fragments of wood and leaves, and binding them together.

That similar travertin is formed at some points in the bed of the sea where calcareous springs issue cannot be doubted, but as a general rule the quantity of lime, according to Bischoff, spread through the waters of the ocean is very small, the free carbonic acid gas in the same waters being five times as much as is necessary to keep the lime in a fluid state. Carbonate of lime therefore can rarely be precipitated at the bottom of the sea by chemical action alone, but must be produced by vital agency as in the case of coral reefs.

In such reefs, large masses of limestone are formed by the stony skeletons of zoophytes; and these, together with shells, become cemented together by carbonate of lime, part of which is probably furnished to the sea water by the decomposition of dead corals. Even shells of which the animals are still living on these reefs, are very commonly found to be encrusted over with a hard coating of limestone.

If sand and pebbles are carried by a river into the sea, and these are bound together immediately by carbonate of lime, the deposit may be described as of a mixed origin, partly chemical, and partly mechanical.

Now, the remarks already made in Chapter II. on the original horizontality of strata are strictly applicable to mechanical deposits, and only partially to those of a mixed nature. Such as are purely chemical may be formed on a very steep slope, or may even encrust the vertical walls of a fissure, and be of equal thickness throughout; but such deposits are of small extent, and for the most part confined to vein-stones.

Consolidation of strata.—It is chiefly in the case of calcareous rocks that solidification takes place at the time of deposition. But there are many deposits in which a cementing process comes into operation long afterwards. We may sometimes observe, where the water of ferruginous or calcareous springs has flowed through a bed of sand or gravel, that iron or carbonate of lime has been deposited in the interstices between the grains or pebbles, so that in certain places the whole has been bound together into a stone, the same set of strata remaining in other parts loose and incoherent.

Proofs of a similar cementing action are seen in a rock at Kelloway in Wiltshire. A peculiar band of sandy strata belonging to the group called Oolite by geologists, may be traced through several counties, the sand being for the most part loose and unconsolidated, but becoming stony near Kelloway. In this district there are numerous fossil shells which have decomposed, having for the most part left only their casts. The calcareous matter hence derived has evidently served, at some former period, as a cement to the siliceous grains of sand, and thus a solid sandstone has been produced. If we take fragments of many other argillaceous grits, retaining the casts of shells, and plunge them into dilute muriatic or other acid, we see them immediately changed into common sand and mud;

the cement of lime, derived from the shells, having been dissolved by the acid.

Traces of impressions and casts are often extremely faint. In some loose sands of recent date we meet with shells in so advanced a stage of decomposition as to crumble into powder when touched. It is clear that water percolating such strata may soon remove the calcareous matter of the shell; and unless circumstances cause the carbonate of lime to be again deposited, the grains of sand will not be cemented together; in which case no memorial of the fossil will remain.

In what manner silex and carbonate of lime may become widely diffused in small quantities through the waters which permeate the earth's crust will be spoken of presently, when the petrifaction of fossil bodies is considered; but I may remark here that such waters are always passing in the case of thermal springs from hotter to colder parts of the interior of the earth; and, as often as the temperature of the solvent is lowered mineral matter has a tendency to separate from it and solidify, Thus a stony cement is often supplied to sand, pebbles, or any fragmentary mixture. In some conglomerates, like the pudding-stone of Hertfordshire (a Lower Eocene deposit), pebbles of flint and grains of sand are united by a siliceous cement so firmly, that if a block be fractured the rent passes as readily through the pebbles as through the cement.

It is probable that many strata became solid at the time when they emerged from the waters in which they were deposited, and when they first formed a part of the dry land. A well-known fact seems to confirm this idea: by far the greater number of the stones used for building and road-making are much softer when first taken from the quarry than after they have been long exposed to the air; and these, when once dried, may afterwards be immersed for any length of time in water without becoming soft again. Hence it is found desirable to shape the stones which are to be used in architecture while they are yet soft, and wet, and while they contain their 'quarry-water,' as it is called; also to break up stone intended for roads when soft, and then leave it to dry in the air for months that it may harden. Such induration may perhaps be accounted for by supposing the water, which penetrates the minutest pores of rocks, to deposit, on evaporation, carbonate of lime, iron, silex, and other minerals previously held in solution, and thereby to fill up the pores partially. These particles, on crystallising, would not only be themselves deprived of freedom of motion, but would also bind together other portions of the rock which before were loosely aggregated. On the same principle wet sand

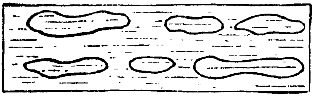
and mud become as hard as stone when frozen; because one ingredient of the mass, namely, the water, has crystallised, so as to hold firmly together all the separate particles of which the loose mud and sand were composed.

Dr. MacCulloch mentions a sandstone in Skye, which may be moulded like dough when first found; and some simple minerals, which are rigid and as hard as glass in our cabinets, are often flexible and soft in their native beds; this is the case with asbestos, sahlite, tremolite, and chalcedony, and it is reported also to happen in the case of the beryl.[1]

The marl recently deposited at the bottom of Lake Superior, in North America, is soft, and often filled with freshwater shells; but if a piece be taken up and dried, it becomes so hard that it can only be broken by a smart blow of the hammer. If the lake therefore was drained, such a deposit would be found to consist of strata of marlstone, like that observed in many ancient European formations, and like them containing freshwater shells.

Concretionary structure.—It is probable that some of the heterogeneous materials which rivers transport to the sea may at once set under water, like the artificial mixture called pozzolana, which consists of fine volcanic sand charged with about 20 per cent. of oxide of iron, and the addition of a small quantity of lime. This substance hardens, and becomes a solid stone in water, and was used by the Romans in constructing the foundations of buildings in the sea. Consolidation in such cases is brought about by the action of chemical affinity on finely comminuted matter previously suspended in water. After deposition similar particles seem often to exert a mutual attraction on each other, and congregate together in particular spots, forming lumps, nodules, and concretions. Thus in many argillaceous deposits there are calcareous balls, or spherical concretions, ranged in layers parallel to the general stratification; an arrangement which took place after the shale or marl had been thrown down in successive laminæ; for these laminæ are often traceable through the concretions, remaining parallel to those of the surrounding unconsolidated rock. (See fig. 48.) Such nodules of limestone have often a shell or other foreign body in the centre.

Fig. 48.



Calcareous nodules in Lias.

Among the most remarkable examples of concretionary structure are those described by Professor Sedgwick as abounding in the magnesian limestone of the north of England. The spherical balls are of various sizes, from that of a pea to a diameter of several feet, and they have both a concentric and radiated structure, while at the same time the laminæ of original deposition pass uninterruptedly through them. In some cliffs this limestone resembles a great irregular pile of cannon balls. Some of the globular masses have their centre in one stratum, while a portion of their exterior passes through to the stratum above or below. Thus the larger spheroid in the annexed section (fig. 49) passes from the stratum *b* upwards into *a*. In this instance we must suppose the deposition of a series of minor layers, first forming the stratum *b*, and afterwards the incumbent stratum *a*; then a movement of the particles took place, and the carbonates of lime and magnesia separated from the more impure and mixed matter forming the still unconsolidated parts of the stratum. Crystallisation, beginning at the centre, must have gone on forming concentric coats around the original nucleus without interfering with the laminated structure of the rock.

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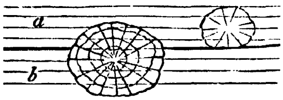
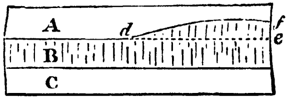
[1] Dr. MacCulloch, Syst of Geol., vol. i. p. 123.



Spheroidal concretions in magnesian limestone.

When the particles of rocks have been thus re-arranged by chemical forces, it is sometimes difficult or impossible to ascertain whether certain lines of division are due to original deposition or to the subsequent aggregation of similar particles. Thus suppose three strata of grit, *A, B, C, are charged unequally with calcareous matter, and that* B is the most calcareous. If consolidation takes place in B, the concretionary action may spread upwards into a part of A, where the carbonate of lime is more abundant than in the rest; so that a mass, *d, e, f*, forming a portion of the superior stratum, becomes united with B into one solid mass of stone. The original line of division *d, e*, being thus effaced, the line *d, f*, would generally be considered as the surface of the bed B, though not strictly a true plane of stratification.

Fig. 50.



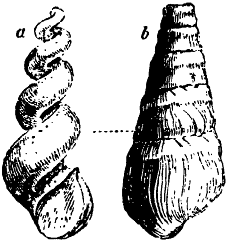
Pressure and heat.—When sand and mud sink to the bottom of a deep sea, the particles are not pressed down by the enormous weight of the incumbent ocean; for the water, which becomes mingled with the sand and mud, resists pressure with a force equal to that of the column of fluid above. The same happens in regard to organic remains which are filled with water under great pressure as they sink, otherwise they would be immediately crushed to pieces and flattened. Nevertheless, if the materials of a stratum remain in a yielding state, and do not set or solidify, they will be gradually squeezed down by the weight of other materials successively heaped upon them, just as soft clay or loose sand on which a house is built may give way. By such downward pressure particles of clay, sand, and marl may become packed into a smaller space, and be made to cohere together permanently.

Analogous effects of condensation may arise when the solid parts of the earth's crust are forced in various directions by those mechanical movements hereafter to be described, by which strata have been bent, broken, and raised above the level of the sea. Rocks of more yielding materials must often have been forced against others previously consolidated, and may thus by compression have acquired a new structure. A recent discovery may help us to comprehend how fine sediment derived from the detritus of rocks may be solidified by mere pressure. The graphite or 'black lead' of commerce having become very scarce, Mr. Brockedon contrived a method by which the dust of the purer portions of the mineral found in Borrowdale might be recomposed into a mass as dense and compact as native graphite. The powder of graphite is first carefully prepared and freed from air, and placed under a powerful press on a strong steel die, with air-tight fittings. It is then struck several blows, each of a power of 1,000 tons; after which operation the powder is so perfectly solidified that it can be cut for pencils, and exhibits when broken the same texture as native graphite.

But the action of heat at various depths in the earth is probably the most powerful of all causes in hardening sedimentary strata. To this subject I shall refer again when treating of the metamorphic rocks, and of the slaty and jointed structure.

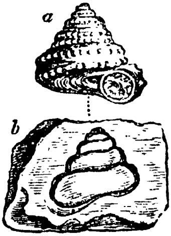
Mineralisation of organic remains.—The changes which fossil organic bodies have undergone since they were first imbedded in rocks, throw much light on the consolidation of strata. Fossil shells in some modern deposits have been scarcely altered in the course of centuries, having simply lost a part of their animal matter. But in other cases the shell has disappeared, and left an impression only of its exterior, or secondly, a cast of its interior form, or thirdly, a cast of the shell itself, the original matter of which has been removed. These different forms of fossilisation may easily be understood if we examine the mud recently thrown out from a pond or canal in which there are shells. If the mud be argillaceous, it acquires consistency on drying, and on breaking open a portion of it we find that each shell has left impressions of its external form. If we then remove the shell itself, we find within a solid nucleus of clay, having the form of the interior of the shell. This form is often very different from that of the outer shell. Thus a cast such as *a*, fig. 51, commonly called a fossil screw, would never be suspected by an inexperienced conchologist to be the internal shape of the fossil univalve, *b*, fig. 51. Nor should we have imagined at first sight that the shell *a* and the cast *b*, fig. 52, belong to one and the same fossil. The reader will observe, in the last-mentioned figure (*b*, fig. 52), that an empty space shaded dark, which the *shell itself* once occupied, now intervenes between the enveloping stone and the cast of the smooth interior of the whorls. In such cases the shell has been dissolved and the component particles removed by water percolating the rock. If the nucleus were taken out, a hollow mould would remain, on which the external form of the shell with its tubercles and striæ, as seen in *a*, fig. 52, would be seen embossed. Now if the space alluded to between the nucleus and the impression, instead of being left empty, has been filled up with calcareous spar, flint, pyrites, or other mineral, we then obtain from the mould an exact cast both of the external and internal form of the original shell. In this manner silicified casts of shells have been formed; and if the mud or sand of the nucleus happen to be incoherent, or soluble in acid, we can then procure in flint an empty shell, which in shape is the exact counterpart of the original. This cast may be compared to a bronze statue, representing merely the superficial form, and not the internal organisation; but there is another description of petrifaction by no means uncommon, and of a much more wonderful kind, which may be compared to certain anatomical models in wax, where not only the outward forms and features, but the nerves, blood-vessels, and other internal

Fig. 51.



Phasianella Heddingtonensis, and cast of the same. Coral Rag.

Fig. 52.

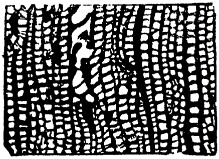


Pleurotomaria Anglica, and cast. Lias.

organs are also shown. Thus we find corals, originally calcareous, in which not only the general shape, but also the minute and complicated internal organisation is retained in flint.

Such a process of petrifaction is still more remarkably exhibited in fossil wood, in which we often perceive not only the rings of annual growth, but all the minute vessels and medullary rays. Many of the minute cells, and fibres of plants, and even those spiral vessels which in the living vegetable can only be discovered by the microscope, are preserved. Among many instances, I may mention a fossil tree, seventy-two feet in length, found at Gosforth, near Newcastle, in sandstone strata associated with coal. By cutting a transverse slice so thin as to transmit light, and magnifying it about fifty-five times, the texture as seen in fig. 53 is exhibited. A texture equally minute and complicated has been observed in the wood of large trunks of fossil trees found in the Craigleth quarry near Edinburgh, where the stone was not in the slightest degree siliceous, but consisted chiefly of carbonate of lime, with oxide of iron, alumina, and carbon. The parallel rows of vessels here seen are the rings of annual growth, but in one part they are imperfectly preserved, the wood having probably decayed before the mineralising matter had penetrated to that portion of the tree.

Fig. 53.



Transverse section of a tree from the coal measures, magnified, showing texture of wood.*

In attempting to explain the process of petrifaction in such cases, we may first assume that strata are very generally permeated by water charged with minute portions of calcareous, siliceous, and other earths in solution. In what manner they become so impregnated will be afterwards considered. If an organic substance is exposed in the open air to the action of the sun and rain, it will in time putrefy, or be dissolved into its component elements, consisting usually of oxygen, hydrogen, nitrogen, and carbon. These will readily be absorbed by the atmosphere or be washed away by rain, so that all vestiges of the dead animal or plant disappear. But if the same substances be submerged in water, they decompose more gradually; and if buried in earth, still more slowly; as in the familiar example of wooden piles or other buried timber. Now, if as fast as each particle is set free by putrefaction in a fluid or gaseous state, a particle equally minute of carbonate of lime, flint, or other

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[1] Witham, Fossil Vegetables, 1831. Plate IV. fig. 1.

mineral, is at hand ready to be precipitated, we may imagine this inorganic matter to take the place just before left unoccupied by the organic molecule. In this manner a cast of the interior of certain vessels may first be taken, and afterwards the more solid walls of the same may decay and suffer a like transmutation. Yet when the whole is lapidified, it may not form one homogeneous mass of stone or metal. Some of the original ligneous, osseous, or other organic elements may remain mingled in certain parts, or the lapidifying substance itself may be differently coloured at different times, or so crystallised as to reflect light differently, and thus the texture of the original body may be faithfully exhibited.

The student may perhaps ask whether, on chemical principles, we have any ground to expect that mineral matter will be thrown down precisely in those spots where organic decomposition is in progress? The following curious experiments may serve to illustrate this point. Professor Göppert of Breslau, with a view of imitating the natural process of petrifaction, steeped a variety of animal and vegetable substances in waters, some holding siliceous, others calcareous, others metallic matter in solution. He found that in the period of a few weeks, or sometimes even days, the organic bodies thus immersed were mineralised to a certain extent. Thus, for example, thin vertical slices of deal, taken from the Scotch fir (*Pinus sylvestrius*), were immersed in a moderately strong solution of sulphate of iron. When they had been thoroughly soaked in the liquid for several days they were dried and exposed to a red-heat until the vegetable matter was burnt up and nothing remained but an oxide of iron, which was found to have taken the form of the deal so exactly that casts even of the dotted vessels peculiar to this family of plants were distinctly visible under the microscope.

The late Dr. Turner observes, that when mineral matter is in a 'nascent state,' that is to say, just liberated from a previous state of chemical combination, it is most ready to unite with other matter, and form a new chemical compound. Probably the particles or atoms just set free are of extreme minuteness, and therefore move more freely, and are more ready to obey any impulse of chemical affinity. Whatever be the cause, it clearly follows, as before stated, that where organic matter newly imbedded in sediment is decomposing, there will chemical changes take place most actively.

An analysis was lately made of the water which was flowing off from the rich mud deposited by the Hooghly river in the Delta of the Ganges after the annual inundation. This water was found to be highly charged with carbonic acid holding lime in solution.[1] Now if newly-deposited mud is thus proved to be permeated by mineral matter in a state of solution, it is not difficult to perceive that decomposing organic bodies, naturally imbedded in sediment, may as readily become petrified as the substances artificially immersed by Professor Göppert in various fluid mixtures.

It is well known that the waters of all springs are more or less charged with earthy, alkaline, or metallic ingredients derived from the rocks and mineral veins through which they percolate. Silex is especially abundant in hot springs, and carbonate of lime is almost always present in greater or less quantity. The materials for the petrification of organic remains are, therefore, usually at hand in a state of chemical solution wherever organic remains are imbedded in new strata.

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[1] Piddington, Asiat. Research, vol. xviii. p. 226.

CHAPTER V.

ELEVATION OF STRATA ABOVE THE SEA—HORIZONTAL AND INCLINED STRATIFICATION.

Why the position of marine strata, above the level of the sea, should be referred to the rising up of the land, not to the going down of the sea—Strata of deep-sea and shallow-water origin alternate—Also marine and freshwater beds and old land surfaces—Vertical, inclined, and folded strata—Anticlinal and synclinal curves—Theories to explain lateral movements—Creeps in coal mines—Dip and strike—Structure of the Jura—Various forms of outcrop—Synclinal strata forming ridges—Connection of fracture and flexure of rocks—Inverted strata—Faults described—Superficial signs of the same obliterated by denudation—Great faults the result of repeated movements—Arrangement and direction of parallel folds of strata—Unconformability—Overlapping strata.

Land has been raised, not the sea lowered.—It has been already stated that the aqueous rocks containing marine fossils extend over wide continental tracts, and are seen in mountain chains rising to great heights above the level of the sea (p. 5). Hence it follows, that what is now dry land was once under water. But if we admit this conclusion, we must imagine, either that there has been a general lowering of the waters of the ocean, or that the solid rocks, once covered by water, have been raised up bodily out of the sea, and have thus become dry land. The earlier geologists, finding themselves reduced to this alternative, embraced the former opinion, assuming that the ocean was originally universal, and had gradually sunk down to its actual level, so that the present islands and continents were left dry. It seemed to them far easier to conceive that the water had gone down, than that solid land had risen upwards into its present position. It was, however, impossible to invent any satisfactory hypothesis to explain the disappearance of so enormous a body of water throughout the globe, it being necessary to infer that the ocean had once stood at whatever height marine shells might be detected. It moreover appeared clear, as the science of Geology advanced, that certain spaces on the globe had been alternately sea, then land, then estuary, then sea again, and, lastly, once more habitable land, having remained in each of these states for considerable periods. In order to account for such phenomena, without admitting any movement of the land itself, we are required to imagine several retreats and returns of the ocean; and even then our theory applies merely to cases where the marine strata composing the dry land are horizontal, leaving unexplained those more common instances where strata are inclined, curved, or placed on their edges, and evidently not in the position in which they were first deposited.

Geologists, therefore, were at last compelled to have recourse to the doctrine that the solid land has been repeatedly moved upwards or downwards, so as permanently to change its position relatively to the sea. There are several distinct grounds for preferring this conclusion. First, it will account equally for the position of those elevated masses of marine origin in which the stratification remains horizontal, and for those in which the strata are disturbed, broken, inclined, or vertical. Secondly, it is consistent with human experience that land should rise gradually in some places and be depressed in others. Such changes have actually occurred in our own days, and are now in progress, having been accompanied in some cases by violent convulsions, while in others they have proceeded so insensibly, as to have been ascertainable only by the most careful scientific observations, made at considerable intervals of time. On the other hand, there is no evidence from human experience of a rising or lowering of the sea's level in any region, and the ocean cannot be raised or depressed in one place without its level being changed all over the globe.

These preliminary remarks will prepare the reader to understand the great theoretical interest attached to all facts connected with the position of strata, whether horizontal or inclined, curved or vertical.

Now the first and most simple appearance is where strata of marine origin occur above the level of the sea in horizontal position. Such are the strata which we meet with in the south of Sicily, filled with shells for the most part of the same species as those now living in the Mediterranean. Some of these rocks rise to the height of more than 2,000 feet above the sea. Other mountain masses might be mentioned, composed of horizontal strata of high antiquity, which contain fossil remains of animals wholly dissimilar from any now known to exist. In the south of Sweden, for example, near Lake Wener, the beds of some of the oldest fossiliferous deposits, called Silurian and Cambrian by geologists, occur in as level a position as if they had recently formed part of the delta of a great river, and been left dry on the retiring of the annual floods. Aqueous rocks of equal antiquity extend for hundreds of miles over the lake-district of

North America, and exhibit in like manner a stratification nearly undisturbed. The Table Mountain at the Cape of Good Hope is another example of highly elevated yet perfectly horizontal strata, no less than 3,500 feet in thickness, and consisting of sandstone of very ancient date.

Instead of imagining that such fossiliferous rocks were always at their present level, and that the sea was once high enough to cover them, we suppose them to have constituted the ancient bed of the ocean, and to have been afterwards uplifted to their present height. This idea, however startling it may at first appear, is quite in accordance, as before stated, with the analogy of changes now going on in certain regions of the globe. Thus, in parts of Sweden, and the shores and islands of the Gulf of Bothnia, proofs have been obtained that the land is experiencing, and has experienced for centuries, a slow upheaving movement.[1]

It appears, from the observations of Mr. Darwin and others, that very extensive regions of the continent of South America have been undergoing slow and gradual upheaval, by which the level plains of Patagonia, covered with recent marine shells, and the Pampas of Buenos Ayres, have been raised above the level of the sea. On the other hand, the gradual sinking of the west coast of Greenland, for the space of more than 600 miles from north to south, during the last four centuries, has been established by the observations of a Danish naturalist, Dr. Pingel. And while these proofs of continental elevation and subsidence, by slow and insensible movements, have been recently brought to light, the evidence has been daily strengthened of continued changes of level effected by violent convulsions in countries where earthquakes are frequent. There the rocks are rent from time to time, and heaved up or thrown down several feet at once, and disturbed in such a manner, as to show how entirely the original position of strata may be modified in the course of centuries.

Mr. Darwin has also inferred that, in those seas where circular coral islands and barrier reefs abound, there is a slow and continued sinking of the submarine mountains on which the masses of coral are based; while there are other areas of the South Sea where the land is on the rise, and where coral of recent species has been upheaved far above the sea-level.

Alternations of marine and freshwater strata.—It has been shown in the third chapter that there is such a difference between land, freshwater, and marine fossils as to enable the geologist to determine whether particular groups of strata were formed at the bottom of the ocean or in estuaries, rivers, or lakes. If surprise was at first created by the discovery of marine corals and shells at the height of several miles above the sea-level, the imagination was afterwards not less startled by observing that in the successive strata composing the earth's crust, especially if their total thickness amounted to thousands of feet, were comprised in some parts formations of shallow-sea as well as of deep-sea origin; also beds of brackish or even of purely freshwater formation, as well as vegetable matter or coal accumulated on ancient land. In these cases we as frequently find freshwater beds below a marine set or shallow water under those of deep-sea origin as the reverse. Thus if we bore an Artesian well below London, we pass through a marine clay, and there reach, at the depth of several hundred feet, a shallow water and fluviatile sand, beneath which comes the white chalk originally formed in a deep sea. Or if we bore vertically through the chalk of the North Downs we come, after traversing marine chalky strata, upon a freshwater formation many hundreds of feet thick called the Wealden, such as is seen in Kent and Surrey, which is known in its turn to rest on purely marine beds. In like manner in various parts of Great Britain we sink vertical shafts through marine deposits of great thickness, and come upon coal, which was formed by the growth of plants on an ancient land-surface sometimes hundreds of square miles in extent.

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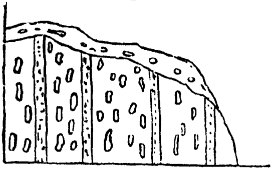
[1] See 'Principles of Geology,' 1867, p. 314.

Vertical, inclined, and curved strata.—*It has been stated that marine strata of different ages are sometimes found at a considerable height above the sea, yet retaining their original* horizontality; but this state of things is quite exceptional. As a general rule strata are inclined or bent in such a manner as to imply that their original position has been altered.

The most unequivocal evidence of such a change is afforded by their standing up vertically showing their edges, which is by no means a rare phenomenon, especially in mountainous countries. Thus we find in Scotland, on the southern skirts of the Grampians, beds of pudding-stone alternating with thin layers of fine sand, all placed vertically to the horizon. When de Saussure first observed certain conglomerates in a similar position in the Swiss Alps, he remarked that the pebbles, being for the most part of an oval shape, had their longer axes parallel to the planes of stratification (see fig. 54). From this he inferred, that such strata

Fig. 54



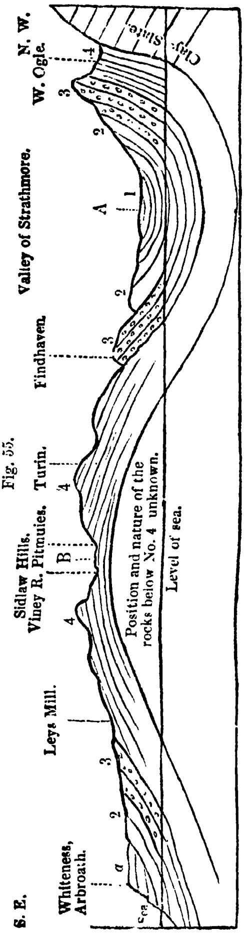
Vertical conglomerate and sandstone.

must, at first, have been horizontal, each oval pebble having settled at the bottom of the water, with its flatter side parallel to the horizon, for the same reason that an egg will not stand on either end if unsupported. Some few, indeed, of the rounded stones in a conglomerate occasionally afford an exception to the above rule, for the same reason that in a river's bed, or on a shingle beach, some pebbles rest on their ends or edges; these having been shoved against or between other stones by a wave or current so as to assume this position.

Anticlinal and synclinal curves.—Vertical strata, when they can be traced continuously upwards or downwards for some depth, are almost invariably seen to be parts of great curves, which may have a diameter of a few yards, or of several miles. I shall first describe two curves of considerable regularity, which occur in Forfarshire, extending over a country twenty miles in breadth, from the foot of the Grampians to the sea near Arbroath.

The mass of strata here shown may be 2,000 feet in thickness, consisting of red and white sandstone, and various coloured shales, the beds being distinguishable into four principal groups, namely, No. 1, red marl or shale; No. 2, red sandstone, used for building; No. 3, conglomerate; and No. 4, grey paving-stone, and tile-stone with green and reddish shale, containing peculiar organic remains. A glance at the section will show that each of the formations 2, 3, 4, are repeated thrice at the surface, twice with a southerly, and once with a northerly inclination or *dip*, and the beds in No. 1, which are nearly horizontal, are still brought up

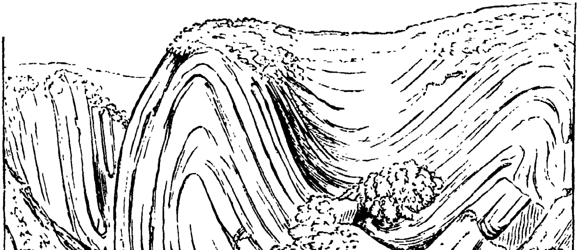
Fig. 55.



Section of Forfarshire, from N. W. to S. E., from foot of the Grampians to the sea at Arbroath (volcanic or trap rocks omitted).
Length of section twenty miles.

twice by a slight curvature to the surface, once on each side of A. Beginning at the north-west extremity, the tile-stones and conglomerates, No. 4 and No. 3, are vertical, and they generally form a ridge parallel to the southern skirts of the Grampians. The superior strata, Nos. 2 and 1, become less and less inclined on descending to the valley of Strathmore, where the strata, having a concave bend, are said by geologists to lie in a 'trough' or 'basin.' Through the centre of this valley runs an imaginary line A, called technically a 'synclinal line,' where the beds, which are tilted in opposite directions, may be supposed to meet. It is most important for the observer to mark such lines, for he will perceive by the diagram, that in travelling from the north to the centre of the basin, he is always passing from older to newer beds; whereas, after crossing the line A, and pursuing his course in the same southerly direction, he is continually leaving the newer, and advancing upon older strata. All the deposits which he had before examined begin then to recur in reversed order, until he arrives at the central axis of the Sidlaw hills, where the strata are seen to form an arch or *saddle*, having an *anticlinal* line B, in the centre. On passing this line, and continuing towards the S. E., the formations 4, 3, and 2, are again repeated, in the same relative order of superposition, but with a southerly dip. At Whiteness (see diagram) it will be seen that the inclined strata are covered by a newer deposit, *a*, in horizontal beds. These are composed of red conglomerate and sand, and are newer than any of the groups, 1, 2, 3, 4, before described, and rest *unconformably* upon strata of the sandstone group, No. 2.

Fig. 56.

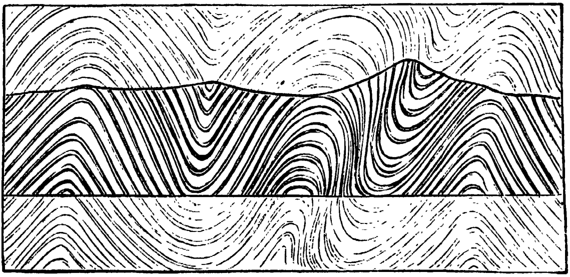


Curved strata of slate near St. Abb's Head, Berwickshire. (Sir J. Hall.)

An example of curved strata, in which the bends or convolutions of the rock are sharper and far more numerous within an equal space, has been well described by Sir James Hall.[1] It occurs near St. Abb's Head, on the east coast of Scotland, where the rocks consist principally of a bluish slate, having frequently a ripple-marked surface. The undulations of the beds reach from the top to the bottom of cliffs from 200 to 300 feet in height, and there are sixteen distinct bendings in the course of about six miles, the curvatures being alternately concave and convex upwards.

Folding by lateral movement.—An experiment was made by Sir James Hall, with a view of illustrating the manner in which such strata, assuming them to have been originally horizontal, may have been forced into their present position. A set of layers of clay were placed under a weight, and their opposite ends pressed towards each other with such force as to cause them to approach more nearly together. On the removal of the weight, the layers of clay were found to be curved and folded, so as to bear a miniature resemblance to the strata in the cliffs. We must however, bear in mind, that in the natural section or sea-cliff we only see the foldings imperfectly, one part being invisible beneath the sea, and the other, or upper portion, being supposed to have been carried away by *denudation*, or that action of water which will be explained in the next chapter. The dark lines in the accompanying plan (fig. 57) represent what is actually seen of the strata in the line of cliff alluded to; the fainter lines denote that portion which is concealed beneath the sea-level, as also that which is supposed to have once existed above the present surface.

Fig. 57.



We may still more easily illustrate the effects which a lateral thrust might produce on flexible strata, by placing several pieces of differently coloured cloths upon a table, and when they are spread out horizontally, cover them with a book. Then apply other books to each end, and force them towards each other. The folding of the cloths (see fig. 58) will imitate those of the bent strata; the incumbent book being slightly lifted up, and no longer touching the two volumes on which it rested before, because it is supported by the tops of the anticlinal ridges formed by the curved cloths. In like manner there can be no doubt that the squeezed strata, although laterally condensed and more closely packed, are yet elongated and made to rise upwards, in a direction perpendicular to the pressure.

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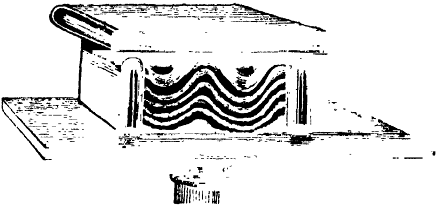
[1] Edin. Trans. vol. vii. pl. 3.

Fig. 58.



Whether the analogous flexures in stratified rocks have really been due to similar sideway movements is a question which we cannot decide by reference to our own observation. Our inability to explain the nature of the process is, perhaps, not simply owing to the inaccessibility of the subterranean regions where the mechanical force is exerted, but to the extreme slowness of the movement. The changes may sometimes be due to variation in the temperature of mountain masses of rock, causing them, while still solid, to expand or contract; or melting them and then again cooling them and allowing them to crystallise. If such be the case, we have scarcely more reason to expect to witness the operation of the process within the limited periods of our scientific observation than to see the swelling of the roots of a tree, by which, in the course of years, a wall of solid masonry may be lifted up, rent, or thrown down. In both instances the force may be irresistible, but though adequate, it need not be visible by us, provided the time required for its development be very great. The lateral pressure arising from the unequal expansion of rocks by heat, may cause one mass lying in the same horizontal plane gradually to occupy a larger space so as to press upon another rock, which, if flexible, may be squeezed into a bent and folded form. It will also appear, when the volcanic and granitic rocks are described, that some of them have, when melted in the interior of the earth's crust, been injected forcibly into fissures, and after the solidification of such intruded matter, other sets of rents, crossing the first, have been formed and in their turn filled by melted rock. Such repeated injections imply a stretching, and often upheaval, of the whole mass.

We also know, especially by the study of regions liable to earthquakes, that there are causes at work in the interior of the earth capable of producing a sinking in of the ground, sometimes very local, but often extending over a wide area. The continuance of such a downward movement, especially if partial and confined to linear areas, may produce regular folds in the strata.

Creeps in coal mines.—The 'Creeps,' as they are called in coal mines, afford an excellent illustration of this fact.—First, it may be stated generally, that the excavation of coal at a considerable depth causes the mass of overlying strata to sink down bodily, even when props are left to support the roof of the mine. 'In Yorkshire,' says Mr. Buddle, 'three distinct subsidences were perceptible at the surface, after the clearing out of three seams of coal below, and innumerable vertical cracks were caused in the incumbent mass of sandstone and shale which thus settled down.'[1] The exact amount of depression in these cases can only be accurately measured where water accumulates on the surface, or a railway traverses a coal-field.

When a bed of coal is worked out, pillars or rectangular masses of coal are left at intervals as props to support the roof, and protect the colliers. Thus, in fig. 59 p. 56, representing a section at Wallsend, Newcastle, the galleries which have been excavated are represented by the white spaces *a b*, while the adjoining dark portions are parts of the original coal seam left as props, beds of sandy clay or shale constituting the floor of the mine. When the props have been reduced in size, they are pressed down by the weight of overlying rocks (no less than 630 feet thick) upon the shale below, which is thereby squeezed and forced up into the open spaces.

Now it might have been expected, that instead of the floor rising up, the ceiling would sink down, and this effect, called a 'Thrust,' does, in fact, take place where the pavement is more solid than the roof. But it usually happens, in coal mines, that the roof is composed of hard shale, or occasionally of sandstone, more unyielding than the foundation, which often consists of clay. Even where the argillaceous substrata are hard at first, they soon become softened and reduced to a plastic state when exposed to the contact of air and water in the floor of a mine.

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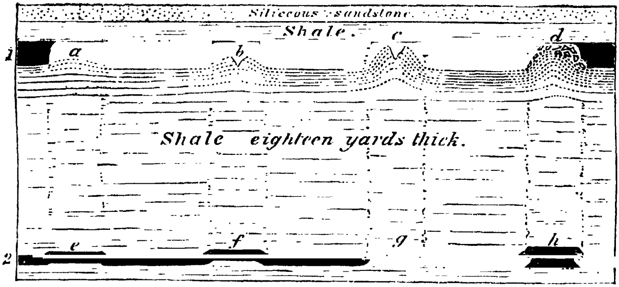
[1] Proceedings of Geol. Soc. vol. iii. p. 148.

The first symptom of a 'creep,' says Mr. Buddle, is a slight curvature at the bottom of each gallery, as at *a*, fig. 59: then the pavement continuing to rise, begins to open with a longitudinal crack, as at *b*; then the points of the fractured ridge reach the roof, as at *c*; and, lastly, the upraised beds close up the whole gallery, and the broken portions of the ridge are reunited and flattened at the top, in the manner shown at *d*. Meanwhile the coal in the props has become crushed and cracked by pressure. It is also found that below the creeps *a*, *b*, *c*, *d*, an inferior stratum, called the 'metal coal,' which is 3 feet thick, has been fractured at the points *e*, *f*, *g*, *h*, and has risen, so as to prove that the upward movement, caused by the working out of the 'main coal,' has been propagated through a thickness of 54 feet of argillaceous beds, which intervene between the two coal seams. This same displacement has also been traced downwards more than 150 feet below the metal coal, but it grows continually less and less until it becomes imperceptible.

Fig. 59.



Section of carboniferous strata at Wallsend, Newcastle, showing 'Creeps.' (J. Buddle, Esq.)

Horizontal length of section, 174 feet. The upper seam, or main coal, here worked out, was 630 feet below the surface.

1. Main coal, 6 feet 6 inches. 2. Metal coal, 3 feet.

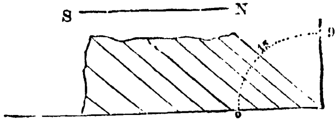
No part of the process above described is more deserving of our notice than the slowness with which the change in the arrangement of the beds is brought about. Days, months, or even years, will sometimes elapse between the first bending of the pavement and the time of its reaching the roof. Where the movement has been most rapid, the curvature of the beds is most regular, and the reunion of the fractured ends most complete ; whereas the signs of displacement or violence are greatest in those creeps which have required months or years for their entire accomplishment. Hence we may conclude that similar changes may have been wrought on a larger scale in the earth's crust by partial and gradual subsidences, especially where the ground has been undermined throughout long periods of time ; and we must be on our guard against inferring sudden violence, simply because the distortion of the beds is excessive.

Engineers are familiar with the fact that when they raise the level of a railway by heaping stone or gravel on a foundation of marsh, quicksand, or other yielding formation, the new mound often sinks for a time as fast as they attempt to elevate it ; when they have persevered so as to overcome this difficulty, they frequently find that some of the adjoining flexible ground has risen up in one or more parallel arches or folds, showing that the vertical pressure of the sinking materials has given rise to a lateral folding movement.

In like manner, in the interior of the earth, the solid parts of the earth's crust may sometimes, as before mentioned, be made to expand by heat, or may be pressed by the force of steam against flexible strata loaded with a great weight of incumbent rocks. In this case the yielding mass, squeezed, but unable to overcome the resistance which it meets with in a vertical direction, may be gradually relieved by lateral folding.

Dip and strike.—In describing the manner in which strata depart from their original horizontality, some technical terms, such as 'dip' and 'strike,' 'anticlinal' and 'synclinal' line or axis, are used by geologists. I shall now proceed to explain some of these to the student. If a stratum or bed of rock, instead of being quite level, be inclined to one side, it is said to *dip* ; the point of the compass to which it is inclined is called the *point of dip*, and the degree of deviation from a level or horizontal line is called *the amount of dip*, or *the angle of dip*. Thus, in the annexed diagram (fig. 60), a series of strata are inclined, and they dip to the north at an angle of forty-five degrees. The *strike*, or *line of bearing*, is the prolongation or extension of the strata in a direction *at right angles* to the dip ;

Fig. 60.



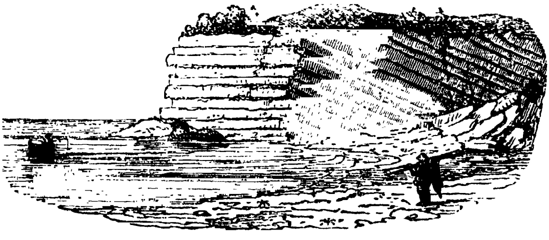
and hence it is sometimes called the *direction* of the strata. Thus, in the above instance of strata dipping to the north, their strike must necessarily be east and west. We have borrowed the word from the German geologists, *streichen* signifying to extend, to have a certain direction. Dip and strike may be aptly illustrated by a row of houses running east and west, the long ridge of the roof representing the strike of the stratum of slates, which dip on one side to the north, and on the other to the south.

A stratum which is horizontal, or quite level in all directions, has neither dip nor strike.

It is always important for the geologist, who is endeavouring to comprehend the structure of a country, to learn how the beds dip in every part of the district; but it requires some practice to avoid being occasionally deceived, both as to the point of dip and the amount of it.

If the upper surface of a hard stony stratum be uncovered, whether artificially in a quarry, or by the waves at the foot of a cliff, it is easy to determine towards what point of the compass the slope is steepest, or in what direction water would flow, if poured upon it. This is the true dip. But the edges of highly inclined strata may give rise to perfectly horizontal lines in the face of a vertical cliff, if the observer see the strata in the line of their strike, the dip being inwards from the face of the cliff. If, however, we come to a break in the cliff, which exhibits a section exactly at right angles to the line of the strike, we are then able to ascertain the true dip. In the annexed drawing (fig. 61), we may suppose a headland, one side of which faces to the north, where the beds would appear perfectly horizontal to a person in the boat; while on the other side facing the west, the true dip would be seen by the person on shore to be at an angle of 40°. If, therefore, our observations are

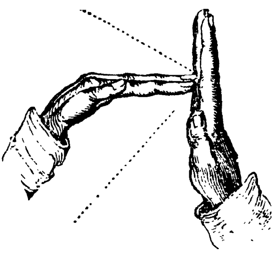
Fig. 61.



Apparent horizontality of inclined strata.

confined to a vertical precipice facing in one direction, we must endeavour to find a ledge or portion of the plane of one of the beds projecting beyond the others, in order to ascertain the true dip.

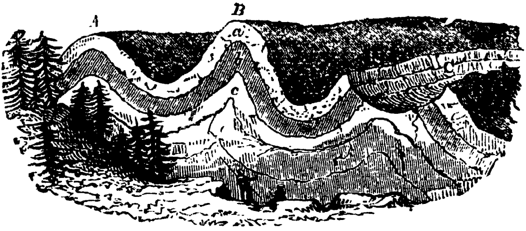
Fig. 62.



If not provided with a clinometer, a most useful instrument when it is of consequence to determine with precision the inclination of the strata, the observer may measure the angle within a few degrees by standing exactly opposite to a cliff where the true dip is exhibited, holding the hands immediately before the eyes, and placing the fingers of one in a perpendicular and of the other in a horizontal position, as in fig. 62. It is thus easy to discover whether the lines of the inclined beds bisect the angle of 90°, formed by the meeting of the hands, so as to give an angle of 45°, or whether it would divide the space into two equal or unequal portions. You have only to change hands to get the dip indicated by the lower dotted line on the upper side of the horizontal hand.

It has been already seen, pp. 52, 53, in describing the curved strata on the east coast of Scotland, in Forfarshire and Berwickshire, that a series of concave and convex bendings are occasionally repeated several times. These usually form part of a series of parallel waves of strata, which are prolonged in the same direction, throughout a considerable extent of country. Thus, for example, in the Swiss Jura, that lofty chain of mountains has been proved to consist of many parallel ridges, with intervening longitudinal valleys, as in fig. 63, the ridges being

Fig. 63.

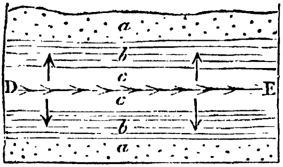


Section illustrating the structure of the Swiss Jura.

formed by curved fossiliferous strata, of which the nature and dip are occasionally displayed in deep transverse gorges, called cluses,' caused by fractures at right angles to the direction of the chain.[1] Now let us suppose these ridges and parallel valleys to run north and south, we should then say that the *strike* of the beds is north and south, and the *dip* east and west. Lines drawn along the summits of the ridges A, B, would be anticlinal lines, and one following the bottom of the adjoining valleys a synclinal line.

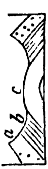
Outcrop of strata.—It will be observed that some of these ridges, A, B (fig. 63), are unbroken on the summit, whereas one of them, C, has been fractured along the line of strike, and a portion of it carried away by denudation, so that the ridges of the beds in the formations *a*, *b*, *c*, come out to the day, or, as the miners say, *crop out*, on the sides of a valley. The ground plan of such a denuded ridge as C, as given in a geological map, may be expressed by the diagram fig. 64, and the cross section of the same by fig. 65. The line D E, fig. 64, is the anticlinal line, on each side of which the dip is in opposite directions, as expressed by the arrows. The emergence of strata at the surface is called by miners their *outcrop* or *basset*.

Fig. 64.



Ground plan of the denuded ridge C, fig. 63.

Fig. 65.



Transverse section.

If, instead of being folded into parallel ridges, the beds form a boss or dome-shaped protuberance, and if we suppose the summit of the dome carried off, the ground plan would exhibit the edges of the strata forming a succession of circles, or ellipses, round a common centre. These circles are the lines of strike, and the dip being always at right angles is inclined in the course of the circuit to every point of the compass, constituting what is termed a quâ-quâversal dip—that is, turning every way.

There are endless variations in the figures described by the basset-edges of the strata, according to the different inclination of the beds, and the mode in which they happen to have been denuded. One of the simplest rules, with which every geologist should be acquainted, relates to the V-like form of the beds as they crop out in an ordinary valley. First, if the strata be horizontal, the V-like form will be also on a level, and the newest strata will appear at the greatest heights.

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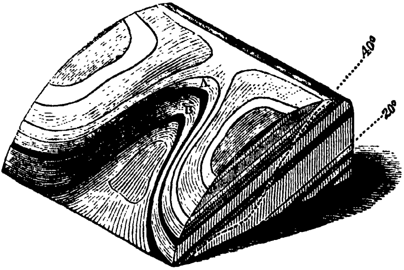
[1] Thurmann, 'Essai sur les Soulèvemens Jurassiques du Porrentruy, Paris, 1832.'

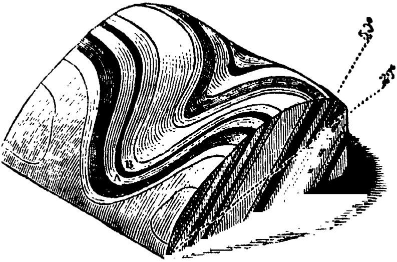
Fig. 66.



Slope of valley 40° dip of strata 20°.

Secondly, if the beds be inclined and intersected by a valley sloping in the same direction, and the dip of the beds be less steep than the slope of the valley, then the V's, as they are often termed by miners, will point upwards (see fig. 66), those formed by the newer beds appearing in a superior position, and extending highest up the valley, as A is seen above B.

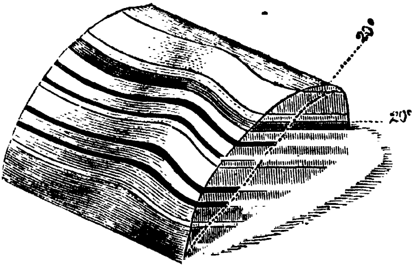
Fig. 67.



Slope of valley 20°, dip of strata 50°.

Thirdly, if the dip of the beds be steeper than the slope of the valley, then the V's will point downwards (see fig. 67), and those formed of the older beds will now appear uppermost, as B appears above A.

Fig. 68.



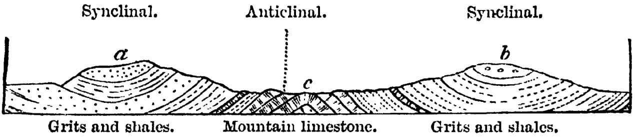
Slope of valley 20°, dip of strata 20°, in opposite directions.

Fourthly, in every case where the strata dip in a contrary direction to the slope of the valley, whatever be the angle of inclination, the newer beds will appear the highest, as in the first and second cases. This is shown by the drawing (fig. 68), which exhibits strata rising at an angle of 20°, and crossed by a valley, which declines in an opposite direction at 20°.

These rules may often be of great practical utility; for the different degrees of dip occurring in the two cases represented in figures 66 and 67 may occasionally be encountered in following the same line of flexure at points a few miles distant from each other. A miner unacquainted with the rule, who had first explored the valley (fig. 66), may have sunk a vertical shaft below the coal seam A, until he reached the inferior bed B. He might then pass to the valley fig. 67, and discovering there also the outcrop of two coal seams, might begin his workings in the uppermost in the expectation of coming down to the other bed A, which would be observed cropping out lower down the valley. But a glance at the section will demonstrate the futility of such hopes.[1]

Synclinal strata forming ridges.—Although in many cases an anticlinal axis forms a ridge, and a synclinal axis a valley, as in A B, fig. 63, p. 59, yet this can by no means be laid down as a general rule, as the beds very often slope inwards from either side of a mountain, as at *a*, *b*, fig. 69, while in the intervening valley *c* they slope upwards, forming an arch.

Fig. 69.



Section of carboniferous rocks of Lancashire. (E. Hull.[2])

It would be natural to expect the fracture of solid rocks to take place chiefly where the bending of the strata has been sharpest, and such rending may produce ravines, giving access to running water and exposing the surface to atmospheric waste. The entire absence, however, of such cracks at points where the strain must have been greatest, as at *a*, fig. 63, is often very remarkable and not always easy of explanation. We must imagine that many strata of limestone, chert, and other rocks which are now brittle, were pliant when bent into their present position. They have owed their flexibility in part to the fluid matter which they contained in their minute pores, as before described (p. 39), and in part to the permeation of sea-water, while they were yet submerged.

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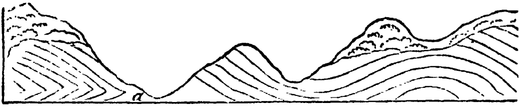
[1] I am indebted to the kindness of T. Sopwith, Esq., for three models which I have copied in the above diagrams; but the beginner may find it by no means easy to understand such copies, although, if he were to examine and handle the originals, turning them about in different ways, he would at once comprehend their meaning as well as the import of others far more complicated, which the same engineer has constructed to illustrate *faults*.

[2] Edward Hull, Quart. Geol. Journ. vol. xxiv. p. 324. 1868.

At the western extremity of the Pyrenees, great curvatures of the strata are seen in the sea-cliffs, where the rocks consist of marl, grit, and chert. At certain points, as at *a*, fig. 70, some of the bendings of the flinty chert are so sharp, that specimens might be broken off, well fitted to serve as ridge-tiles on the roof of a house. Although this chert could not have been brittle as now, when first folded into this shape, it presents, nevertheless, here and there at the points of greatest flexure small cracks, which show that it was solid, and not wholly incapable of breaking at the period of its displacement. The numerous rents alluded to are not empty, but filled with calcedony and quartz.

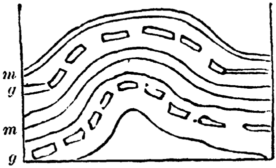
Fig. 70.



Strata of chert, grit, and marl, near St. Jean de Luz.

Between San Caterina and Castrogiovanni, in Sicily, bent and undulating gypseous marls occur, with here and there thin beds of solid gypsum interstratified. Sometimes these solid layers have been broken into detached fragments, still preserving their sharp edges (*g g*, fig. 71), while the continuity of the more pliable and ductile marls, *m m*, has not been interrupted.

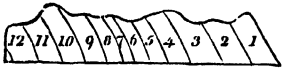
Fig. 71.



g gypsum. *m* marl.

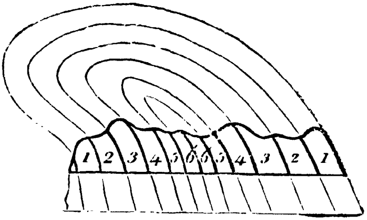
We have already explained, fig. 69, that stratified rocks have usually their strata bent into parallel folds forming anticlinal and synclinal axes, a group of several of these folds having often been subjected to a common movement, and having acquired a uniform strike or direction. In some disturbed regions these folds have been doubled back upon themselves in such a manner that it is often difficult for an experienced geologist to determine correctly the relative age of the beds by superposition. Thus if we meet with the strata seen in the section, fig. 72, we should naturally suppose that there were twelve distinct beds, or sets of beds, No. 1 being the newest, and No. 12 the oldest of the series. But this section may perhaps exhibit merely six beds, which have been folded in the manner seen in fig. 73, so that each of them is twice repeated, the position of one half being reversed, and part of No. 1, originally the uppermost, having now become the lowest of the series.

Fig. 72.



These phenomena are observable on a magnificent scale in certain regions in Switzerland, in precipices often more than 2,000 feet in perpendicular height, and there are flexures not inferior in dimensions in the Pyrenees. The upper part of the curves seen in this diagram, fig. 73, and expressed in fainter lines, has been removed by what is called denudation, to be afterwards explained.

Fig. 73.

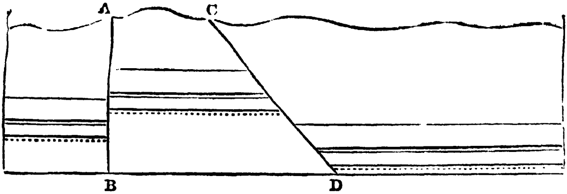


Fractures of the strata and faults.—Numerous rents may often be seen in rocks which appear to have been simply broken, the fractured parts still remaining in contact; but we often find a fissure, several inches or yards wide, intervening between the disunited portions. These fissures are usually filled with fine earth and sand, or with angular fragments of stone, evidently derived from the fracture of the contiguous rocks.

The face of each wall of the fissure is often beautifully polished, as if glazed, striated, or scored with parallel furrows and ridges, such as would be produced by the continued rubbing together of surfaces of unequal hardness. These polished surfaces are called by miners 'slickensides.' It is supposed that the lines of the striæ indicate the direction in which the rocks were moved. During one of the minor earthquakes in Chili, in 1840, the brick walls of a building were rent vertically in several places, and made to vibrate for several minutes during each shock, after which they remained uninjured, and without any opening, although the line of each crack was still visible. When all movement had ceased, there were seen on the floor of the house, at the bottom of each rent, small heaps of fine brick-dust, evidently produced by trituration.

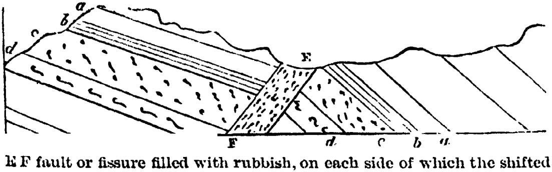
It is not uncommon to find the mass of rock, on one side of a fissure, thrown up above or down below the mass with which it was once in contact on the other side. 'This mode of displacement is called a fault, shift, slip, or throw.' 'The miner,' says Playfair, describing a fault, 'is often perplexed, in his subterraneous journey, by a derangement in the strata, which changes at once all those lines and bearings which had hitherto directed his course. When his mine reaches a certain plane, which is sometimes perpendicular, as in A B, fig. 74, sometimes oblique to the horizon (as in C D, ibid.), he finds the beds of rock broken asunder, those on the one side of the plane having changed their place, by sliding in a particular direction along the face of the others. In this motion they have sometimes preserved their parallelism, as in fig. 74, so that the strata on each side of the faults A B, C D, continue parallel to one another; in other cases, the strata on each side are inclined, as in *a*, *b*, *c*, *d* (fig. 75), though their identity is still to be recognised by their possessing the same thickness and the same internal characters.'[1]

Fig. 74.



Faults. A B perpendicular, C D oblique to the horizon.

Fig. 75.



E F fault or fissure filled with rubbish, on each side of which the shifted strata are not parallel.

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[1] Playfair, Illust. of Hutt. Theory, § 42.

In Coalbrook Dale, says Mr. Prestwich,[1] deposits of sandstone, shale and coal, several thousand feet thick, and occupying an area of many miles, have been shivered into fragments, and the broken remnants have been placed in very discordant positions, often at levels differing several hundred feet from each other. The sides of the faults, when perpendicular, are commonly several yards apart, and are sometimes as much as 50 yards asunder, the interval being filled with broken *débris* of the strata. In following the course of the same fault it is sometimes found to produce in different places very unequal changes of level, the amount of shift being in one place 300, and in another 700 feet, which arises from the union of two or more faults. In other words, the disjointed strata have in certain districts been subjected to renewed movements, which they have not suffered elsewhere.

We may occasionally see exact counterparts of these slips on a small scale, in pits of loose sand and gravel, many of which have doubtless been caused by the drying and shrinking of argillaceous and other beds, slight subsidences having taken place from failure of support. Sometimes, however, even these small slips may have been produced during earthquakes ; for land has been moved, and its level, relatively to the sea, considerably altered, within the period when much of the alluvial sand and gravel now covering the surface of continents was deposited.

I have already stated that a geologist must be on his guard, in a region of disturbed strata, against inferring repeated alternations of rocks, when, in fact, the same strata, once continuous, have been bent round so as to recur in the same section, and with the same dip. A similar mistake has often been occasioned by a series of faults.

If, for example, the dark line A H (fig. 76) represent the surface of a country on which the strata *a b c* frequently crop out, an observer, who is proceeding from H to A, might at first imagine that at every step he was approaching new strata, whereas the repetition of the same beds has been caused by vertical faults, or downthrows. Thus, suppose the original mass, A, B, C, D, to have been a set of uniformly inclined strata, and that the different masses under E F, F G, and G D, sank down successively, so as to leave vacant the spaces marked in the diagram by dotted lines, and to occupy those marked by the continuous lines, then let denudation take place along the line A H, so that the protruding masses indicated by the fainter lines are swept away,—a miner, who has not discovered the faults, finding the mass *a*, which we will suppose to be a bed of coal four times repeated, might hope to find four beds, workable to an indefinite depth, but first on arriving at the fault G he is stopped suddenly in his workings, for he comes partly upon

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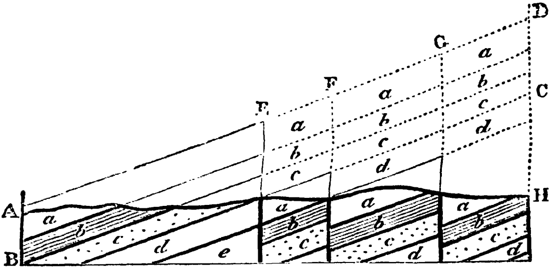
[1] Geol. Trans. second series, vol. v. p. 452.

Fig. 76.



Apparent alternations of strata caused by vertical faults.

the shale *b*, and partly on the sandstone *c*; the same result awaits him at the fault F, and on reaching E he is again stopped by a wall composed of the rock *d*.

The very different levels at which the separated parts of the same strata are found on the different sides of the fissure, in some faults, are truly astonishing. One of the most celebrated in England is that called the 'ninety-fathom dike,' in the coal-field of Newcastle. This name has been given to it, because the same beds are ninety fathoms (540 feet) lower on the northern than they are on the southern side. The fissure has been filled by a body of sand, which is now in the state of sandstone, and is called the dike, which is sometimes very narrow, but in other places more than twenty yards wide.[1] The walls of the fissure are scored by grooves, such as would have been produced if the broken ends of the rock had been rubbed along the plane of the fault.[2] In the Tynedale and Craven faults, in the north of England, the vertical displacement is still greater, and the fracture has extended in a horizontal direction for a distance of thirty miles or more.

Great faults the result of repeated movements.—It must not, however, be supposed that faults generally consist of single linear rents; there are usually a number of faults springing off from the main one, and sometimes a long strip of country seems broken up into fragments by sets of parallel and connecting transverse faults. Oftentimes a great line of fault has been repeated or the movements have been continued through successive periods, so that newer deposits having covered the old line of displacement the strata both newer and older have given way along the old line of fracture. Some geologists have considered it necessary to imagine that the upward or downward movement in these cases was accomplished at a single stroke, and not by a series of sudden but interrupted movements. They appear to have derived this idea from a notion that the grooved walls have merely been rubbed in one direction, which is far from being a constant phenomenon. Not only are some sets of striæ not parallel to others, but the clay and rubbish between the walls, when squeezed or rubbed, have been streaked in different directions, the grooves which the harder minerals have impressed on the softer being frequently curved and irregular.

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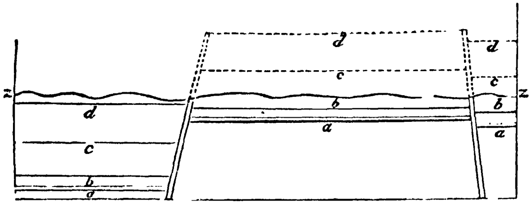
[1] Conybeare and Phillips, Outlines, &c., p. 376.

[2] Phillips, Geology, Lardner's Cyclop., p. 41.

The usual absence of protruding masses of rock forming precipices or ridges along the lines of great faults has already been alluded to in explaining fig. 76, p. 67, and the same remarkable fact is well exemplified in every coal-field which has been extensively worked. It is in such districts that the former relation of the beds which have been shifted is determinable with great accuracy. Thus in the coal-field of Ashby de la Zouch, in Leicestershire (see fig. 77), a fault occurs, on one side of which the coal-beds *a b c d* must once have risen to the height of 500 feet above the corresponding beds on the other side. But the uplifted strata do not stand up 500 feet above the general surface ; on the contrary, the outline of the country, as expressed by the line *z z*, is uniformly undulating without any break, and the mass indicated by the dotted outline must have been washed away.[1]

Fig. 77.



Faults and denuded coal strata, Ashby de la Zouch. (Mammatt.)

The student may refer to Mr. Hull's measurement of faults, observed in the Lancashire coal-field, where the vertical displacement has amounted to thousands of feet, and yet where all the superficial inequalities which must have resulted from such movements have been obliterated by subsequent denudation. In the same memoir proofs are afforded of there having been two periods of vertical movement in the same fault, one, for example, before, and another after, the Triassic epoch.[1]

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[1] See Mammatt's Geological Facts, &c., p. 90 and plate.

The shifting of the beds by faults is often intimately connected with those same foldings which constitute the anticlinal and synclinal axes before alluded to, and there is no doubt that the subterranean causes of both forms of disturbance are to a great extent the same. A fault in Virginia, believed to imply a displacement of several thousand feet, has been traced for more than eighty miles in the same direction as the foldings of the Appalachian chain.[2] An hypothesis which attributes such a change of position to a succession of movements, is far preferable to any theory which assumes each fault to have been accomplished by a single upcast or downthrow of several thousand feet. For we know that there are operations now in progress, at great depths in the interior of the earth, by which both large and small tracts of ground are made to rise above and sink below their former level, some slowly and insensibly, others suddenly and by starts, a few feet or yards at a time; whereas there are no grounds for believing that, during the last 3,000 years at least, any regions have been either upheaved or depressed, at a single stroke, to the amount of several hundred much less several thousand feet.

It is certainly not easy to understand how in the subterranean regions one mass of solid rock should have been folded up by a continued series of movements, while another mass in contact, or only separated by a line of fissure, has remained stationary or has perhaps subsided. But every volcano, by the intermittent action of the steam, gases, and lava evolved during an eruption, helps us to form some idea of the manner in which such operations take place. For eruptions are repeated at uncertain intervals throughout the whole or a large part of a geological period, some of the surrounding and contiguous districts remaining quite undisturbed. And in most of the instances with which we are best acquainted the emission of lava, scoria, and steam is accompanied by the uplifting of the solid crust. Thus in Vesuvius, Etna, the Madeiras, the Canary Islands, and the Azores there is evidence of marine deposits of recent and tertiary date having been elevated to the height of a thousand feet, and sometimes more, since the commencement of the volcanic explosions. There is, moreover, a general tendency in contemporaneous volcanic vents to affect a linear arrangement extending in some instances, as in the Andes or the Indian Archipelago, to distances equalling half the circumference of the globe. Where volcanic heat, therefore, operates at such a depth as not to obtain vent at the surface, in the form of an eruption, it may nevertheless be conceived to give rise to upheavals, foldings, and faults in certain linear tracts. And marine denudation, to be treated of in the next chapter, will help us to understand why that which should be the protruding portion of the faulted rocks is missing at the surface.

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[1] Hull, Quart. Geol. Journ. vol. xxiv. p. 318. 1868.

[2] H. D. Rogers, Geol. of Pennsylvania, p. 897.

Arrangement and direction of parallel folds of strata.—The possible causes of the folding of strata by lateral movements have been considered in a former part of this chapter. No chain of mountains affords so remarkable an illustration of the persistency of such flexures for a great distance as the Appalachians before alluded to, and none has been studied and described by many good observers with more accuracy. The chain extends from north to south, or rather N.N.E. to S.S.W., for nearly 1,500 miles, with a breadth of 50 miles, *throughout which the Palæozoic strata have been so bent as to form a series of parallel anticlinal and synclinal ridges and* troughs, comprising usually three or four principal and many smaller plications, some of them forming broad and gentle arches, others narrower and steeper ones, while some, where the bending has been greatest, have the position of their beds inverted as before shown in fig. 73, p. 64.

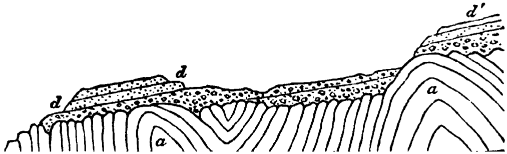
The strike of the parallel ridges, after continuing in a straight line for many hundred miles, is then found to vary for a more limited distance as much as 30°, the folds wheeling round together in the new direction and continuing to be parallel as if they had all obeyed the same movement. The date of the movements by which the great flexures were brought about must, of course, be subsequent to the formation of the uppermost part of the Coal or the newest of the bent rocks, but the disturbance must have ceased before the Triassic strata were deposited on the denuded edges of the folded beds.

The manner in which the numerous parallel folds all simultaneously formed assume a new direction common to the whole of them, and sometimes varying at an angle of 30° from the normal strike of the chain, shows what deviation from an otherwise uniform strike of the beds may be experienced when the geographical area through which they are traced is on so vast a scale.

The disturbances in the case here adverted to occurred between the Carboniferous period and that of the Trias, and this interval is so vast that they may have occupied a great lapse of time, during which their parallelism was always preserved. But as a rule wherever after a long geological interval the recurrence of lateral movements gives rise to a new set of folds, the strike of these last is different. Thus, for example, Mr. Hull has pointed out that three principal lines of disturbance, all later than the Carboniferous period, have affected the stratified rocks of Lancashire. The first of these, having an E.N.E. direction, took place at the close of the Carboniferous period. The next, running north and south, at the close of the Permian, and the third, having a N.N.W. direction, at the close of the Jurassic period.[1]

Unconformability of strata.—Strata are said to be unconformable, when one series is so placed over another, that the planes of the superior repose on the edges of the inferior (see fig. 78). In this case it is evident that a period had elapsed between the production of the two sets of strata, and that, during this interval, the older series had been tilted and disturbed. Afterwards the upper series was thrown down in horizontal strata upon it. If these superior beds, *d*, *d*, fig. 78, are also inclined, it is plain that the lower strata, *a*, *a*, have been twice displaced; first, before the deposition of the newer beds, *d*, *d*, and a second time when these same strata were upraised out of the sea, and thrown slightly out of the horizontal postion.

Fig. 78.



Unconformable junction of old red sandstone and Silurian schist at the Siccar Point, near St. Abb's Head, Berwickshire.

It often happens that in the interval between the deposition of two sets of unconformable strata, the inferior rock has not only been denuded, but drilled by perforating shells. Thus, for example, at Autreppe and Gusigny, near Mons, beds of an ancient (primary or palæozoic) limestone, highly inclined, and often bent, are covered with horizontal strata of greenish and whitish marls of the Cretaceous formation. The lowest, and therefore the oldest, bed of the horizontal series is usually the sand and conglomerate, *a*, in which are rounded fragments of stone, from an inch to two feet in diameter. These fragments have often adhering shells attached to them, and have been bored by perforating mollusca. The solid surface of the inferior limestone has also been bored, so as to exhibit cylindrical and pear-shaped cavities, as at *c*, the work of saxicavous mollusca; and many rents, as at *b*, which descend several feet or yards into the limestone, have been filled with sand and shells, similar to those in the stratum *a*.

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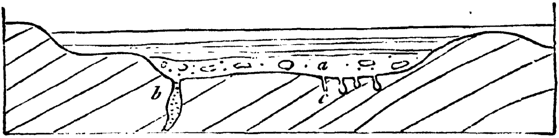
[1] Edward Hull, Quart. Geol. Journ. vol. xxiv. p. 323.

Fig. 79.



Junction of unconformable strata near Mons, in Belgium.

Overlapping strata.—Strata are said to overlap, when an upper bed of a series extends beyond the limits of a lower one. This may be produced in various ways, as, for example, when alterations of physical geography cause the arms of a river or channels of discharge to vary, so that sediment brought down is deposited over a wider area than before, or when the sea-bottom has been raised up and again depressed without disturbing the horizontal position of the strata. In this case the newer strata may rest for the most part conformably on the older, but, extending farther, pass over their edges. Every intermediate state between unconformable and overlapping beds may occur, because there may be every gradation between a slight derangement of position, and a considerable disturbance and denudation of the older formation, before the newer beds come on.

CHAPTER VI.

DENUDATION.

Denudation defined—Its amount more than equal to the entire mass of stratified deposits in the earth's crust—Subaërial denudation—Action of the wind—Action of running water—Alluvium defined—Different ages of alluvium—Denuding power of rivers affected by rise or fall of land—Littoral denudation—Inland sea-cliffs—Escarpments—Submarine denudation—Dogger-bank—Newfoundland bank—Denuding power of the ocean during emergence of land.

DENUDATION, which has been occasionally spoken of in the preceding chapters, is the removal of solid matter by water motion, whether of rivers or of the waves and currents of the sea, and the consequent laying bare of some inferior rock. This operation has exerted an influence on the structure of the earth's crust as universal and important as sedimentary deposition itself; for denudation is the necessary antecedent of the production of all new strata of mechanical origin. The formation of every new deposit by the transport of sediment and pebbles necessarily implies that there has been, somewhere else, a grinding down of rock into rounded fragments, sand, or mud, equal in quantity to the new strata. All deposition, therefore, except in the case of a shower of volcanic ashes, and the outflow of lava, and the growth of certain organic formations, is the sign of superficial waste going on contemporaneously, and to an equal amount, elsewhere. The gain at one point is no more than sufficient to balance the loss at some other. Here a lake has grown shallower, there a ravine has been deepened. Here the depth of the sea has been augmented by the removal of a sand-bank during a storm, there its bottom has been raised and shallowed by the accumulation in its bed of the same sand transported from the bank.

When we see a stone building, we know that somewhere, far or near, a quarry has been opened. The courses of stone in the building may be compared to successive strata, the quarry to a ravine or valley which has suffered denudation. As the strata, like the courses of hewn stone, have been laid one upon another gradually, so the excavation both of the valley and quarry has been gradual. To pursue the comparison still farther, the superficial heaps of mud, sand, and gravel, usually called alluvium, may be likened to the rubbish of a quarry which has been rejected as useless by the workmen, or has fallen upon the road between the quarry and the building, so as to lie scattered at random over the ground.

But we occasionally find in a conglomerate large rounded pebbles of an older conglomerate, which had previously been derived from a variety of different rocks. In such cases we are reminded that the same materials having been used over and over again, it is not enough to affirm that the entire mass of stratified deposits in the earth's crust affords a monument and measure of the denudation which has taken place, for in truth the quantity of matter now extant in the form of stratified rock represents but a fraction of the material removed by water and redeposited in past ages.

Subaërial denudation.—Denudation may be divided into subaërial, or the action of wind, rain, and rivers, and submarine, or that effected by the waves of the sea, and its tides and currents. With the operation of the first of these we are best acquainted, and it may be well to give it our first attention.

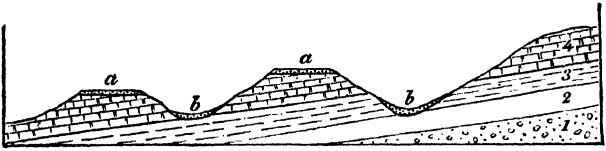
Action of the wind.—In desert regions where no rain falls, or where, as in parts of the Sahara, the soil is so salt as to be without any covering of vegetation, clouds of dust and sand attest the power of the wind to cause the shifting of the unconsolidated or disintegrated rock.

In examining volcanic countries I have been much struck with the great superficial changes brought about by this power in the course of centuries. The highest peak of Madeira is about 6,050 feet above the sea, and consists of the skeleton of a volcanic cone now 250 feet high, the beds of which once dipped from a centre in all directions at an angle of more than 30°. The summit is formed of a dike of basalt with much olivine, fifteen feet wide, apparently the remains of a column of lava which once rose to the crater. Nearly all the scoriæ of the upper part of the cone have been swept away, those portions only remaining which were hardened by the contact or proximity of the dike. While I was myself on this peak on January 25, 1854, I saw the wind, though it was not stormy weather, removing sand and dust derived from the decomposing scoriæ. There had been frost in the night, and some ice was still seen in the crevices of the rock.

On the highest platform of the Grand Canary, at an elevation of 6,000 feet, there is a cylindrical column of hard lava, from which the softer matter has been carried away; and other similar remnants of the dikes of cones of eruption attest the denuding power of the wind at points where running water could never have exerted any influence. The waste effected by wind, aided by frost and snow, may not be trifling, even in a single winter, and when multiplied by centuries, may become indefinitely great.

Action of running water.—There are different classes of phenomena which attest in a most striking manner the vast spaces left vacant by the erosive power of water. I may allude, first, to those valleys on both sides of which the same strata are seen following each other in the same order, and having the same mineral composition and fossil contents. We may observe, for example, several formations, as Nos. 1, 2, 3, 4, in the accompanying diagram (fig. 80); No. 1, conglomerate, No. 2, clay, No. 3, grit, and No. 4, limestone, each repeated in a series of hills separated by valleys varying in depth. When we examine the subordinate parts of these four formations, we find, in like manner, distinct beds in each, corresponding, on the opposite sides of the valleys, both in composition and order of position. No one can doubt that the strata were originally continuous, and that some cause has swept away the portions which once connected the whole series. A torrent on the side of a mountain produces similar interruptions; and when we make artificial cuts in lowering roads, we often expose, in like manner, corresponding beds on either side. But in nature, these appearances occur in mountains several thousand feet high, and separated by intervals of many miles or leagues in extent.

Fig. 80.



a Older alluvium or drift. *b* Modern alluvium.

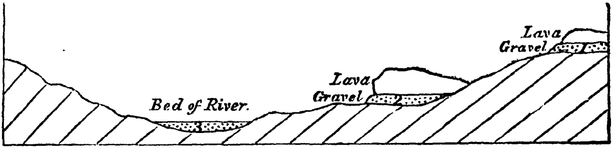
In the 'Memoirs of the Geological Survey of Great Britain' (vol. i.), Professor Ramsay has shown that the missing beds removed from the summit of the Mendips must have been nearly a mile in thickness; and he has pointed out considerable areas in South Wales, and some of the adjacent counties of England, where a series of primary (or palæozoic) strata, not less than 11,000 feet in thickness, have been stripped off. All these materials have of course been transported to new regions, and have entered into the composition of more modern formations. On the other hand, it is shown by observations in the same '*Survey*,' *that the Palæozoic strata are from 20,000 to 30,000* feet thick. It is clear that such rocks, formed of mud and sand, now for the most part consolidated, are the monuments of denuding operations, which must have taken place at some of the remotest periods of the earth's history yet known to us. For whatever has been given to one area must always have been borrowed from another; a truth which, obvious as it may seem when thus stated, must be repeatedly impressed on the student's mind, because in many geological speculations it is taken for granted that the external crust of the earth has been always growing thicker in consequence of the accumulation, period after period, of sedimentary matter, as if the new strata were not always produced at the expense of pre-existing rocks, stratified or unstratified. By duly reflecting on the fact, that all deposits of mechanical origin imply the transportation from some other region, whether contiguous or remote, of an equal amount of solid matter, we perceive that the stony exterior of the planet must always have grown thinner in one place, whenever, by accessions of new strata, it was acquiring thickness in another.

It is well known that generally at the mouths of large rivers, deltas are forming and the land is encroaching upon the sea; these deltas are monuments of recent denudation and deposition; and it is obvious that if the mud, sand, and gravel were taken from them and restored to the continents they would fill up a large part of the gulleys and valleys which are due to the excavating and transporting power of torrents and rivers.

Alluvium.—Between the superficial covering of vegetable mould and the subjacent rock there usually intervenes in every district a deposit of loose gravel, sand, and mud, to which when it occurs in valleys the name of alluvium has been popularly applied. The term is derived from *alluvio*, an inundation, or *alluo*, to wash, because the pebbles and sand commonly resemble those of a river's bed or the mud and gravel washed over low lands by a flood.

In the course of those changes in physical geography which may take place during the gradual emergence of the bottom of the sea and its conversion into dry land, any spot may either have been a sunken reef, or a bay, or estuary, or sea-shore, or the bed of a river. The drainage, moreover, may have been deranged again and again by earthquakes, during which temporary lakes are caused by landslips, and partial deluges occasioned by the bursting of the barriers of such lakes. For this reason it would be unreasonable to hope that we should ever be able to account for all the alluvial phenomena of each particular country, seeing that the causes of their origin are so various. Besides, the last operations of water have a tendency to disturb and confound together all pre-existing alluviums. Hence we are always in danger of regarding as the work of a single era, and the effect of one cause, what has in reality been the result of a variety of distinct agents, during a long succession of geological epochs. Much useful instruction may therefore be gained from the exploration of a country like Auvergne, where the superficial gravel of very different eras happens to have been preserved and kept separate by sheets of lava, which were poured out one after the other at periods when the denudation, and probably the upheaval, of rocks were in progress. That region had already acquired in some degree its present configuration before any volcanoes were in activity, and before any igneous matter was superimposed upon the granitic and fossiliferous formations. The pebbles therefore in the older gravels are exclusively constituted of granite and other aboriginal rocks; and afterwards, when volcanic vents burst forth into eruption, those earlier alluviums were covered by streams of lava, which protected them from intermixture with gravel of subsequent date. In the course of ages, a new system of valleys was excavated, so that the rivers ran at lower levels than those at which the first alluviums and sheets of lava were formed. When, therefore, fresh eruptions gave rise to new lava, the melted matter was poured out over lower grounds; and the gravel of these plains differed from the first or upland alluvium, by containing in it rounded fragments of various volcanic rocks, and often fossil bones belonging to species of land animals different from those which had previously flourished in the same country, and been buried in older gravels.

Fig. 81.



Lavas of Auvergne resting on alluviums of different ages.

The annexed drawing (fig. 81) will explain the different heights at which beds of lava and gravel, each distinct from the other in composition and age, are observed, some on the flat tops of hills 700 or 800 feet high, others on the slope of the same hills, and the newest of all in the channel of the existing river, where there is usually gravel alone, although in some cases a narrow strip of solid lava shares the bottom of the valley with the river.

The proportion of extinct species of quadrupeds is more numerous in the fossil remains of the gravel No. 1 than in that indicated as No. 2; and in No. 3 they agree more closely, sometimes entirely, with those of the existing fauna. The usual absence or rarity of organic remains in beds of loose gravel and sand is partly owing to the friction which originally ground down the rocks into small fragments, and partly to the porous nature of alluvium, which allows the free percolation through it of rain-water, and promotes the decomposition and removal of fossil remains.

The loose transported matter on the surface of a large part of the land now existing in the temperate and arctic regions of the northern hemisphere, must be regarded as being in a somewhat exceptional state, in consequence of the important part which ice has played in comparatively modern geological times. This subject will be more specially alluded to when we describe in the eleventh chapter the deposits called 'glacial.'

Denuding power of rivers affected by rise or fall of land.—It has long been a matter of common observation that most rivers are now cutting their channels through alluvial deposits of greater depth and extent than could ever have been formed by the present streams. From this fact it has been inferred that rivers in general have grown smaller, or become less liable to be flooded than formerly. It may be true that in the history of almost every country the rivers have been both larger and smaller than they are at the present moment. For the rainfall in particular regions varies according to climate and physical geography, and is especially governed by the elevation of the land above the sea, or its distance from it, and other conditions equally fluctuating in the course of time. But the phenomenon alluded to may sometimes be accounted for by oscillations in the level of the land, experienced since the existing valleys originated, even where no marked diminution in the quantity of rain and in the size of the rivers has occurred.

We know that many large areas of land are rising and others sinking, and unless it could be assumed that both the upward or downward movements are everywhere uniform, many of the existing hydrographical basins ought to have the appearance of having been temporary lakes first filled with fluviatile strata and then partially re-excavated.

Suppose, for example, part of a continent, comprising within it a large hydrographical basin like that of the Mississippi, to subside several inches or feet in a century, as the west coast of Greenland, extending 600 miles north and south, has been sinking for three or four centuries, between the latitudes 60° and 69° N.[1] It will rarely happen that the rate of subsidence will be everywhere equal, and in many cases the amount of depression in the interior will regularly exceed that of the region nearer the sea. Whenever this happens, the fall of the waters flowing from the upland country will be diminished, and each tributary stream will have less power to carry its sand and sediment into the main river, and the main river less power to convey its annual burden of transported matter to the sea. All the rivers, therefore, will proceed to fill up partially their ancient channels, and, during frequent inundations, will raise their alluvial plains by new deposits. If, then, the same area of land be again upheaved to its former height, the fall, and consequently the velocity, of every river will begin to augment. Each of them will be less given to overflow its alluvial plain; and their power of carrying earthy matter seaward, and of scouring out and deepening their channels, will be sustained till, after a lapse of many thousand years, each of them has eroded a new channel or valley through a fluviatile formation of comparatively modern date. The surface of what was once the river-plain at the period of greatest depression, will then remain fringing the valley-sides in the form of a terrace apparently flat, but in reality sloping down with the general inclination of the river. Everywhere this terrace will present cliffs of gravel and sand, facing the river. That such a series of movements has actually taken place in the main valley of the Mississippi and in its tributary valleys during oscillations of level, I have endeavoured to show in my description of that country;[2] and the freshwater shells of existing species and bones of land quadrupeds, partly of extinct races, preserved in the terraces of fluviatile origin, attest the exclusion of the sea during the whole process of filling up and partial re-excavation.

Littoral denudation.—Part of the action of the waves between high and low water mark must be included in subaërial denudation, more especially as the undermining of cliffs by the waves is facilitated by land-springs, and these often lead to the sliding down of great masses of land into the sea. Along our coasts we find numerous submerged forests, only visible at low water, having the trunks of the trees erect and their roots attached to them, and still spreading through the ancient soil as when they were living. They occur in too many places, and sometimes at too great a depth, to be explained by a mere change in the level of the tides, although as the coasts waste away and alter in shape, the height to which the tides rise and fall is always varying, and the level of high tide at any given point may, in the course of many ages, differ by several feet or even fathoms. It is this fluctuation in the height of the tides, and the erosion and destruction of the sea-coast by the waves, that makes it exceedingly difficult for us in a few centuries, or even perhaps in a few thousand years, to determine whether there is a change by subterranean movement in the relative level of sea and land.

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[1] Principles of Geology, 7th ed. p. 506; 10th ed. vol. ii. p. 196.

[2] Second Visit to the U. S. vol. i. chap. xxxiv.

We often behold, as on the coasts of Devonshire and Pembrokeshire, facts which appear to lead to opposite conclusions. In one place a raised beach with marine littoral shells, and in another immediately adjoining a submerged forest. These phenomena indicate oscillations of level, and as the movements are very gradual, they must give repeated opportunities to the breakers to denude the land, which is thus again and again exposed to their fury, although it is evident that the submergence is sometimes effected in such a manner as to allow the trees which border the coast not to be carried away.

Inland sea-cliffs.—In countries where hard limestone rocks abound, inland cliffs have often retained faithfully for ages the characters which they acquired when they constituted the boundary of land and sea. Thus, in the Morea, no less than three or even four ranges of cliffs are well preserved, rising one above the other at different distances from the actual shore, the summit of the highest and oldest occasionally attaining the height of 1,000 feet. A consolidated beach with marine shells is usually found at the base of each cliff, and a line of littoral caverns. These ranges of cliff probably imply pauses in the process of upheaval when the waves and currents had time to undermine and clear away considerable masses of rock.

But the beginner should be warned not to expect to find evidence of the former sojourn of the sea on all those lands which we are nevertheless sure have been submerged at periods comparatively modern; for notwithstanding the enduring nature of the marks left by littoral action on some rocks, especially limestones, we can by no means detect sea-beaches and inland cliffs everywhere. On the contrary, they are, upon the whole, extremely partial, and are often entirely wanting in districts composed of argillaceous and sandy formations, which must, nevertheless, have been upheaved at the same time, and by the same intermittent movements, as the adjoining harder rocks.

s.—Besides the inland cliffs above alluded to which mark the ancient limits of the sea, there are other abrupt terminations of rocks of various kinds which resemble sea-cliffs, but which have in reality been due to subaërial denudation. These have been called 'escarpments,' a term which it is useful to confine to the outcrop of particular formations having a scarped outline, as distinct from cliffs due to marine action.

I formerly supposed that the steep line of cliff-like slopes seen along the outcrop of the chalk, when we follow the edge of the North or South Downs, was due to marine action; but Professor Ramsay has shown[1] that the present outline of the physical geography is more in favour of the idea of the escarpments having been due to gradual waste since the rocks were exposed in the atmosphere to the action of rain and rivers.

Mr. Whitaker has given a good summary of the grounds for ascribing these apparent sea-cliffs to waste in the open air. 1. There is an absence of all signs of ancient sea-beaches or littoral deposits at the base of the escarpment. 2. Great inequality is observed in the level of the base line. 3. The escarpments do not intersect, like sea-cliffs, a series of distinct rocks, but are always confined to the boundary line of the same formation. 4. There are sometimes different contiguous and parallel escarpments—those, for example, of the greensand and chalk—which are so near each other, and occasionally so similar in altitude, that we cannot imagine any existing archipelago if converted into dry land to present a like outline.

The above theory is by no means inconsistent with the opinion that the limits of the outcrop of the chalk and greensand which the escarpments now follow, were originally determined by marine denudation. When the south-east of England last emerged from beneath the level of the sea, it was acted upon, no doubt, by the tide, waves, and currents, and the chalk would form from the first a mass projecting above the more destructible clay called gault. Still the present escarpments so much resembling sea-cliffs have no doubt, for reasons above stated, derived their most characteristic features subsequently to emergence from subaërial waste by rain and rivers.

Submarine denudation.—When we attempt to estimate the amount of submarine denudation, we become sensible of the disadvantage under which we labour from our habitual incapacity of observing the action of marine currents on the bed of the sea. We know that the agitation of the waves, even during storms, diminishes at a rapid rate, so as to become very insignificant at the depth of a few fathoms, and is quite imperceptible at sea as a denuding agent, geologically considered, is not dependent on the power of currents to preserve at great depths a velocity sufficient to remove sand and mud, because, even where the deposition or removal of sediment is not in progress, the depth of water does not remain constant throughout geological time. Every page of the geological record proves to us that the relative levels of land and sea, and the position of the ocean and of continents and islands, have been always varying, and we may feel sure that some portions of the submarine area are now rising and others sinking. The force of tidal and other currents and of the waves during storms is sufficient to prevent the emergence of many lands, even though they may be undergoing continual upheaval. It is not an uncommon error to imagine that the waste of sea-cliffs affords the measure of the amount of marine denudation, of which it probably constitutes an insignificant portion.

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[1] Physical Geography and Geology of Great Britain, p. 78. 1864.

Dogger-bank. — That great shoal called the Dogger-bank, about sixty miles east of the coast of Northumberland, and occupying an area about as large as Wales, has nowhere a depth of more than ninety feet, and in its shallower parts is less than forty feet under water. It might contribute towards the safety of the navigation of our seas to form an artificial island, and to erect a lighthouse on this bank ; but no engineer would be rash enough to attempt it, as he would feel sure that the ocean in the first heavy gale would sweep it away as readily as it does every temporary shoal that accumulates from time to time around a sunk vessel on the same bank.[1]

No observed geographical changes in historical times entitle us to assume that where upheaval may be in progress it proceeds at a rapid rate. Three or four feet rather than as many yards in a century may probably be as much as we can reckon upon in our speculations; and if such be the case, the continuance of the upward movement might easily be counteracted by the denuding force of such currents aided by such waves as during a gale are known to prevail in the German Ocean. What parts of the bed of the ocean are stationary at present, and what areas may be rising or sinking, is a matter of which we are very ignorant, as the taking of accurate soundings is but of recent date.

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[1] Principles, 10th ed. vol. i. p. 569.

Newfoundland-bank.—The great bank of Newfoundland may be compared in size to the whole of England. This part of the bottom of the Atlantic is surrounded on three sides by a rapidly deepening ocean, the bank itself being from twenty to fifty fathoms (or from 120 to 300 feet) under water. We are unable to determine by the comparison of different charts, made at distant periods, whether it is undergoing any change of level, but if it be gradually rising we cannot anticipate on that account that it will become land, because the breakers in an open sea would exercise a prodigious force even on solid rock brought up to within a few yards of the surface. We know, for example, that when a new volcanic island rose in the Mediterranean in 1831, the waves were capable in a few years of reducing it to a sunken rock.

In the same way currents which flow over the Newfoundland bank a great part of the year at the rate of two miles an hour, and are known to retain a considerable velocity to near the bottom, may carry away all loose sand and mud and make the emergence of the shoal impossible, in spite of the accessions of mud, sand, and boulders derived occasionally from melting icebergs which, coming from the northern glaciers, are frequently stranded on various parts of the bank. They must often leave at the bottom large erratic blocks which the marine currents may be incapable of moving, but the same rocky fragments may be made to sink by the undermining of beds consisting of finer matter on which the blocks and gravel repose. It is by no means improbable that the annual removal of an average thickness of half an inch of rock might counteract the ordinary upheaval which large submarine areas are undergoing; and the real enigma which the geologist has to solve is not the extensive denudation of the white chalk or of our tertiary sands and clays, but the fact that such incoherent materials have ever succeeded in lifting up their heads above water in an open sea. Why were they not swept away during storms into some adjoining abysses, the highest parts of each shoal being always planed off down to the depth of a few fathoms? The hardness and toughness of some rocks already exposed to windward and acting as breakwaters may perhaps have assisted; nor must we forget the protection afforded by a dense and unbroken covering of barnacles, limpets, and other creatures which flourish most between high and low water and shelter some newly risen coasts from the waves.

CHAPTER VII.

JOINT ACTION OF DENUDATION, UPHEAVAL, AND SUBSIDENCE IN REMODELLING THE EARTH'S CRUST.

How we obtain an insight at the surface, of the arrangement of rocks at great depths—Why the height of the successive strata in a given region is so disproportionate to their thickness—Computation of the average annual amount of subaërial denudation—Antagonism of volcanic force to the levelling power of running water—How far the transfer of sediment from the land to a neighbouring sea-bottom may affect subterranean movements—Permanence of continental and oceanic areas.

How we obtain an insight at the surface of the arrangement of rocks at great depths.—The reader has been already informed that in the structure of the earth's crust we often find proofs of the direct superposition of marine to freshwater strata, and also evidence of the alternation of deep-sea and shallow-water formations. In order to explain how such a series of rocks could be made to form our present continents and islands, we have not only to assume that there have been alternate upward and downward movements of great vertical extent, but that the upheaval in the areas which we at present inhabit has, in later geological times, sufficiently predominated over subsidence as to cause these portions of the earth's crust to be land instead of sea. The sinking down of a delta beneath the sea-level may cause strata of fluviatile or even terrestrial origin, such as peat with trees proper to marshes, to be covered by deposits of deep-sea origin. There is also no end to the thickness of mud and sand which may accumulate in shallow water, provided that fresh sediment is brought down from the wasting land at a rate corresponding to that of the sinking of the bed of the sea. The latter, again, may sometimes sink so fast that the earthy matter, being intercepted in some new landward depression, may never reach its former resting-place, where, the water becoming clear, may favour the growth of shells and corals, and calcareous rocks of organic origin may thus be superimposed on mechanical deposits.

The succession of strata here alluded to would be consistent with the occurrence of gradual downward and upward movements of the land and bed of the sea without any disturbance of the horizontality of the several formations. But the arrangement of rocks composing the earth's crust differs materially from that which would result from a mere series of vertical movements. Had the volcanic forces been confined to such movements, and had the stratified rocks been first formed beneath the sea and then raised above it, without any lateral compression, the geologist would never have obtained an insight into the monuments of various ages, some of extremely remote antiquity.

What we have said in Chapter V. of dip and strike, of the folding and inversion of strata, of anticlinal and synclinal flexures, and in Chapter VI. of denudation at different periods, whether subaërial or submarine, must be understood before the student can comprehend what may at first seem to him an anomaly, but which it is his business particularly to understand. I allude to the small height above the level of the sea attained by strata, often many miles in thickness, and about the chronological succession of which, in one and the same region, there is no doubt whatever. Had stratified rocks in general remained horizontal, the waves of the sea would have been enabled during oscillations of level to plane off entirely the uppermost beds as they rose or sank during the emergence or submergence of the land. But the occurrence of a series of formations of widely different ages, all remaining horizontal and in conformable stratification, is exceptional, and for this reason the total annihilation of the uppermost strata has rarely taken place. We owe, indeed, to the sideway movements of *lateral compression* those anticlinal and synclinal curves of the beds already described (fig. 55, p. 51), which, together with denudation, subaërial and submarine, enable us to investigate the structure of the earth's crust many miles below those points which the miner can reach. I have already shown in fig. 56, p. 52, how, at St. Abb's Head, a series of strata of indefinite thickness may become vertical, and then denuded, so that the edges of the beds alone shall be exposed to view, the altitude of the upheaved ridges being reduced to a moderate height above the sea-level; and it may be observed that although the incumbent strata of Old Red Sandstone are in that place nearly horizontal, yet these same newer beds will in other places be found so folded as to present vertical strata, the edges of which are abruptly cut off, as in 2, 3, 4 on the right-hand side of the diagram, fig. 55, p. 51.

Why the height of the successive strata in a given region is so disproportionate to their thickness.—We cannot too distinctly bear in mind how dependent we are on the joint action of the volcanic and aqueous forces, the one in disturbing the original position of rocks, and the other in destroying large portions of them, for our power of consulting the different pages and volumes of those stony records of which the crust of the globe is composed. Why, it may be asked, if the ancient bed of the sea has been in many regions uplifted to the height of two or three miles, and sometimes twice that altitude, and if it can be proved that some single formations are of themselves two or three miles thick, do we so often find several important groups resting one upon the other, yet attaining only the height of a few hundred feet above the level of the sea?

The American geologists, after carefully studying the Alleghany or Appalachian mountains, have ascertained that the older fossiliferous rocks of that chain (from the Silurian to the Carboniferous inclusive) are not less than 42,000 feet thick, and if they were now superimposed on each other in the order in which they were thrown down, they ought to equal in height the Himalayas with the Alps piled upon them. Yet they rarely reach an altitude of 5,000 feet, and their loftiest peaks are no more than 7,000 feet high. The Carboniferous strata forming the highest member of the series, and containing beds of coal, can be shown to be of shallow-water origin, or even sometimes to have originated in swamps in the open air. But what is more surprising, the lowest part of this great Palæozoic series, instead of having been thrown down at the bottom of an abyss more than 40,000 feet deep, consists of sediment (the Potsdam sandstone), evidently spread out on the bottom of a shallow sea, on which ripple-marked sands were occasionally formed. This vast thickness of 40,000 feet is not obtained by adding together the maximum density attained by each formation in distant parts of the chain, but by measuring the successive groups as they are exposed in a very limited area, and where the denuded edges of the vertical strata forming the parallel folds alluded to at p. 70, 'crop out' at the surface. Our attention has been called by Mr. James Hall, Paleontologist of New York, to the fact that these Palæozoic rocks of the Appalachian chain, which are of such enormous density, where they are almost entirely of mechanical origin, thin out gradually as they are traced to the westward, where evidently the contemporaneous seas allowed organic rocks to be formed by corals, echinoderms, and encrinites in clearer water, and where, although the same successive periods are represented, the total mass of strata from the Silurian to the Carboniferous, instead of being 40,000 is only 4,000 feet thick.

A like phenomenon is exhibited in every mountainous country, as, for example, in the European Alps; but we need not go farther than the north of England for its illustration. Thus in Lancashire and central England the thickness of the Carboniferous formation, including the Millstone Grit and Yoredale beds, is computed to be more than 18,000 feet; to this we may add the Mountain Limestone, at least 2,000 feet in thickness, and the overlying Permian and Triassic formations, 3,000 or 4,000 feet thick. How, then, does it happen that the loftiest hills of Yorkshire and Lancashire, instead of being 24,000 feet high, never rise above 3,000 feet? For here, as before pointed out in the Alleghanies, all the great thicknesses are sometimes found in close approximation and in a region only a few miles in diameter. It is true that these same sets of strata do not preserve their full force when followed for indefinite distances. Thus the 18,000 feet of Carboniferous grits and shales in Lancashire, before alluded to, gradually thin out, as Mr. Hull has shown, as they extend southward, by attenuation or original deficiency of sediment, and not in consequence of subsequent denudation, so that when we have followed them for about 100 miles into Leicestershire, they have dwindled away to a thickness of only 3,000 feet. In the same region the Carboniferous limestone attains so unusual a thickness—namely, more than 4,000 feet—as to appear to compensate in some measure for the deficiency of contemporaneous sedimentary rock.[1]

It is admitted that when two formations are unconformable their fossil remains almost always differ considerably. The break in the continuity of the organic forms seems connected with a great lapse of time, and the same interval has allowed extensive disturbance of the strata, and removal of parts of them by denudation, to take place. The more we extend our investigations the more numerous do the proofs of these breaks become, and they extend to the most ancient rocks yet discovered. The oldest examples yet brought to light in the British Isles are on the borders of Ross-shire and Sutherlandshire, and have been well described by Sir Roderick Murchison, by whom their chronological relations were admirably worked out, and proved to be very different from those which previous observers had imagined them to be. I had an opportunity in the autumn of 1869 of verifying the splendid section given in fig. 82 by climbing in a few hours from the banks of Loch Assynt to the summit of the mountain called Queenaig, 2,673 feet high.

The formations 1, 2, 3, the Laurentian, Cambrian, and Silurian, to be explained in Chapters XXV. and XXVI., not only occur in succession in this one mountain, but their unconformable junctions are distinctly exposed to view.

To begin with the oldest set of rocks, No. 1; they consist chiefly of hornblendic gneiss, and in the neighbouring Hebrides form whole islands, attaining a thickness of thousands of feet, although they have suffered such contortions and denudation that they seldom rise more than a few hundred feet above the sea-level. In discordant stratification upon the edges of this gneiss reposes No. 2, a group of conglomerate and purple sandstone referable to the Cambrian (or Longmynd) formation, which can elsewhere be shown to be characterised by its peculiar organic remains. On this again rests No. 3, a lower member of the important group called Silurian, an outlier of which, 3′, caps the summit of Queenaig, attesting the removal by denudation of rocks of the same age, which once extended from the great mass 3 to 3′. Although this rock now consists of solid quartz, it is clear that in its original state it was formed of fine sand, perforated by numerous lob-worms or annelids, which left their burrows in the shape of tubular hollows (see Chapter XXV. figure of *Arenicolites*), hundreds, nay thousands, of which I saw as I ascended the mountain.

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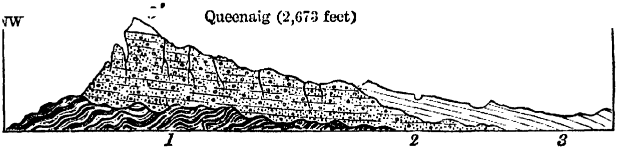
[1] Hull, Quart. Geol. Journ. vol. xxiv. p. 322. 1868.

Fig. 82.

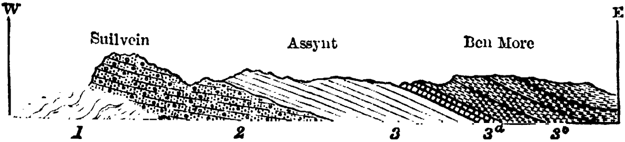


Unconformable Palæozoic strata, Sutherlandshire (Murchison).

1. Laurentian gneiss. 2. Cambrian conglomerate and sandstone. 3, 3′. Lower Quartzose (Silurian) with annelid burrows.

In Queenaig we only behold this lower quartzose member of the Silurian rocks, but I am informed by the Rev. W. S. Symonds that there are sections near the base of Queenaig, where the fossiliferous limestones (3*a*, fig. 83) are seen to overlie the lower quartz rock of Queenaig, 3, while these limestones are

Fig. 83.



Diagrammatic section of the same groups near Queenaig (Murchison).

1. Laurentian gneiss. 2. Cambrian conglomerate and sandstone. 3. Lower Quartzose (Silurian) with annelid burrows. 3*a*. Fossiliferous Silurian limestone. 3*b*. Upper Quartzose (altered Silurian) with traps.

themselves surmounted by an upper quartzite, 3*b*, which rises into the heights of Glashven and Ben More. Eastward this upper quartz rock is overlaid by an upper gneiss, which has been confounded with the lower Laurentian gneiss of Assynt (1, figs. 82, 83). The upper gneiss is, however, more micaceous, and differs in its mineralogical character, being less crystalline and contorted. It is very seldom that in the same country one continuous formation, such as the Silurian, is, as in this case, more fossiliferous and less altered by volcanic heat in its older than in its newer strata, and still more rare to find an underlying and unconformable group like the Cambrian retaining its original condition of a conglomerate and sandstone more perfectly than the overlying formation. Here also we may remark in regard to the origin of these Cambrian rocks that they were evidently produced at the expense of the underlying Laurentian, for the rounded pebbles occurring in them are identical in composition and texture with that crystalline gneiss which constitutes the contorted beds of the inferior formation No. 1. When the reader has studied the chapter on metamorphism, and has become aware how much modification by heat, pressure, and chemical action is required before the conversion of sedimentary into crystalline strata can be brought about, he will appreciate the insight which we thus gain into the date of the changes which had already been effected in the Laurentian rocks long before the Cambrian pebbles of quartz and gneiss were derived from them. The Laurentian is estimated by Sir William Logan to amount in Canada to 30,000 feet in thickness. As to the Cambrian it is supposed by Sir Roderick Murchison that the fragment left in Sutherlandshire is about 3,500 feet thick, and in Wales and the borders of Shropshire this formation may equal 10,000 feet, while the Silurian strata, No. 3, difficult as it may be to measure them in their various foldings to the eastward, where they have been invaded by intrusive masses of granite, are supposed many times to surpass the Cambrian in volume and density.

But although we are dealing here with stratified rocks, each of which would be several miles in thickness if they were fully represented, the whole of them do not attain the elevation of a single mile above the level of the sea.

Computation of the average annual amount of subaërial denudation.—The geology of the district above alluded to may assist our imagination in conceiving the extent to which groups of ancient rocks, each of which may in their turn have formed continents and oceanic basins, have been disturbed, folded, and denuded even in the course of a few out of many of those geological periods to which our imperfect records relate. It is not easy for us to over-estimate the effects which causes in everyday action must produce when the multiplying power of time is taken into account.

Attempts were made by Manfredi in 1736, and afterwards by Playfair, in 1802, to calculate the time which it would require to enable the rivers to deliver over the whole of the land into the basin of the ocean. The data were at first too imperfect and vague to allow them even to approximate to safe conclusions. But in our own time similar investigations have been renewed with more prospect of success, the amount brought down by many large rivers to the sea having been more accurately ascertained. Mr. Alfred Tylor, in 1850, inferred that the quantity of detritus now being distributed over the sea-bottom would, at the end of 10,000 years, cause an elevation of the sea-level to the extent of at least three inches.[1] Subsequently, Mr. Croll in 1867, and again, with more exactness, in 1868, deduced from the latest measurement of the sediment transported by European and American rivers, the rate of subaërial denudation to which the surface of large continents is exposed, taking especially the hydrographical basin of the Mississippi as affording the best available measure of the average waste of the land. The conclusion arrived at in his able memoir,[2] was that the whole terrestrial surface is denuded at the rate of one foot in 6,000 years, and this opinion was simultaneously enforced by his fellow-labourer, Mr. Geikie, who, being jointly engaged in the same line of enquiry, published a luminous essay on the subject in 1868.

The student, by referring to my 'Principles of Geology,'[3] may see that Messrs. Humphrey and Abbot, during their survey of the Mississippi, attempted to make accurate measurements of the proportion of sediment carried down annually to the sea by that river, including not only the mud held in suspension, but also the sand and gravel forced along the bottom.

It is evident that when we know the dimensions of the area which is drained, and the annual quantity of earthy matter taken from it and borne into the sea, we can affirm how much on an average has been removed from the general surface in one year, and there seems no danger of our overrating the mean rate of waste by selecting the Mississippi as our example, for that river drains a country equal to more than half the continent of Europe, extends through twenty degrees of latitude, and therefore through regions enjoying a great variety of climate, and some of its tributaries descend from mountains of great height. The Mississippi is also more likely to afford us a fair test of ordinary denudation, because, unlike the St. Lawrence and its tributaries, there are no great lakes in which the fluviatile sediment is thrown down and arrested on its way to the sea. In striking a general average we have to remember that there are large deserts in which there is scarcely any rainfall, and tracts which are as rainless as parts of Peru, and these must not be neglected as counterbalancing others, in the tropics, where the quantity of rain is in excess. If then, argues Mr. Geikie, we assume that the Mississippi is lowering the surface of the great basin which it drains at the rate of 1 foot in 6,000 years, 10 feet in 60,000 years, 100 feet in 600,000 years, and 1,000 feet in 6,000,000 years, it would not require more than about 4,500,000 years to wear away the whole of the North American continent, if its mean height is correctly estimated by Humboldt at 748 feet. And if the mean height of all the land now above the sea throughout the globe is 1,000 feet, as some geographers believe, it would only require six million years to subject a mass of rock equal in volume to the whole of the land to the action of subaërial denudation. It may be objected that the annual waste is partial, and not equally derived from the general surface of the country, inasmuch as plains, watersheds, and level ground at all heights remain comparatively unaltered ; but this, as Mr. Geikie has well pointed out, does not affect our estimate of the sum total of denudation. The amount remains the same, and if we allow too little for the loss from the surface of table-lands we only increase the proportion of the loss sustained by the sides and bottoms of the valleys, and *vice versâ*.[1]

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[1] Tylor, Phil. Mag. 4th series, p. 268. 1850.

[2] Croll, Phil. Mag. 1868, p. 381.

[3] Vol. i. p. 454. 1872.

Antagonism of volcanic force to the levelling power of running water.—In all these estimates it is assumed that the entire quantity of land above the sea-level remains on an average undiminished in spite of annual waste. Were it otherwise the subaërial denudation would be continually lessened by the diminution of the height and dimensions of the land exposed to waste. Unfortunately we have as yet no accurate data enabling us to measure the action of that force by which the inequalities of the surface of the earth's crust may be restored and the height of the continents and depth of the seas made to continue unimpaired. I stated in 1830 in the 'Principles of Geology,'[2] that running water and volcanic action are two antagonistic forces ; the one labouring continually to reduce the whole of the land to the level of the sea, the other to restore and maintain the inequalities of the crust on which the very existence of islands and continents depends. I stated, however, that when we endeavour to form some idea of the relation of these destroying and renovating forces, we must always bear in mind that it is not simply by upheaval that subterranean movements can counteract the levelling force of running water. For whereas the transportation of sediment from the land to the ocean would raise the general sea-level, the subsidence of the sea-bottom by increasing its capacity would check this rise and prevent the submergence of the land. I have, indeed, endeavoured to show that unless we assume that there is, on the whole, more subsidence than upheaval, we must suppose the diameter of the planet to be always increasing, by that quantity of volcanic matter which is annually poured out in the shape of lava or ashes, whether on the land or in the bed of the sea, and which is derived from the interior of the earth. The abstraction of this matter causes, no doubt, subterranean vacuities and a corresponding giving way of the surface ; if it were not so, the average density of parts of the interior would be always lessening and the size of the planet increasing.[1]

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[1] Trans. Geol. Soc. Glasgow, vol. iii. p. 169.

[2] 1st ed. chap. x. p. 167, 1830; see also 11th ed. vol. i. chap. xv. p. 321. 1867.

Our inability to estimate the amount or direction of the movements due to volcanic power by no means renders its efficacy as a land-preserving force in past times a mere matter of conjecture. The student will see in Chapter XXIV. that we have proofs of Carboniferous forests hundreds of miles in extent which grew on the lowlands or deltas near the sea, and which subsided and gave place to other forests, until in some regions fluviatile and shallow-water strata, with occasional seams of coal, were piled one over the other, till they attained a thickness of many thousand feet. Such accumulations, observed in Great Britain and America on opposite sides of the Atlantic, imply the long-continued existence of land vegetation, and of rivers draining a former continent placed where there is now deep sea.

It will be also seen in Chapter XXV. that we have evidence of a rich terrestrial flora, the Devonian, even more ancient than the Carboniferous ; while, on the other hand, the later Triassic, Oolitic, Cretaceous, and successive Tertiary periods have all supplied us with fossil plants, insects, or terrestrial mammalia ; showing, that in spite of great oscillations of level and continued changes in the position of land and sea, the volcanic forces have maintained a due proportion of dry land. We may appeal also to freshwater formations, such as the Purbeck and Wealden, to prove that in the Oolitic and Neocomian eras there were rivers draining ancient lands in Europe in times when we know that other spaces, now above water, were submerged.

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[1] Principles, vol. ii. p. 240. 1872 ; also 1st ed. p. 447. 1830.

How far the transfer of sediment from the land to a neighbouring sea-bottom may affect subterranean movements.—Little as we understand at present the laws which govern the distribution of volcanic heat in the interior and crust of the globe, by which mountain chains, high table-lands, and the abysses of the ocean are formed, it seems clear that this heat is the prime mover on which all the grander features in the external configuration of the planet depend.

It has been suggested that the stripping off by denudation of dense masses from one part of a continent and the delivery of the same into the bed of the ocean must have a decided effect in causing changes of temperature in the earth's crust below, or, in other words, in causing the subterranean isothermals to shift their position. If this be so, one part of the crust may be made to rise, and another to sink, by the expansion and contraction of the rocks, of which the temperature is altered.

I cannot, at present, discuss this subject, of which I have treated more fully elsewhere,[1] but may state here that I believe this transfer of sediment to play a very subordinate part in modifying those movements on which the configuration of the earth's crust depends. In order that strata of shallow-water origin should be able to attain a thickness of several thousand feet, and so come to exert a considerable downward pressure, there must have been first some independent and antecedent causes at work which have given rise to the incipient, shallow receptacle in which the sediment began to accumulate. The same causes there continuing to depress the sea-bottom, room would be made for fresh accessions of sediment, and it would only be by a long repetition of the depositing process that the new matter could accumulate in sufficient quantity to check the outward escape of heat, and thus to affect the temperature of the rocks far below, so as to increase or diminish their volume.

Permanence of continental and oceanic areas.—If the thickness of more than 40,000 feet of sedimentary strata before alluded to in the Appalachians proves a preponderance of downward movements in Palæozoic times in a district now forming the eastern border of North America, it also proves, as before hinted, the continued existence and waste of some neighbouring continent, probably formed of Laurentian rocks, and situated where the Atlantic now prevails. Such an hypothesis would be in perfect harmony with the conclusions forced upon us by the study of the present configuration of our continents, and the relation of their height to the depth of the oceanic basins;—also to the considerable elevation and extent sometimes reached by drift containing shells of recent species, and still more by the fact of sedimentary strata, several thousand feet thick, as those of central Sicily, or such as flank the Alps and Apennines, containing fossil mollusca sometimes almost wholly identical with species still living.

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[1] Principles, vol. ii. p. 231. 1872.

I have remarked elsewhere[1] that upward and downward movements of 1,000 feet or more would turn much land into sea, and sea into land in the continental areas and their borders, whereas oscillations of equal magnitude would have no corresponding effect in the bed of the ocean generally, believed as it is to have a mean depth of 15,000 or at least 12,000 feet. It is probable, from soundings made during the laying of electric telegraph cables and dredging expeditions, that the greatest depths of the sea do not exceed the greatest heights of the land; it may, therefore, seem strange that the mean depth of the sea should exceed the mean height of the land twelve times, even taking the lowest estimate of the ocean depths as given by the late deep-sea soundings.[2] This apparent anomaly arises from the fact that the extreme heights of the land are exceptional and confined to a small part of its surface; while the ocean maintains its great depth over enormous areas. The capacity of the basin of the ocean may be perhaps best understood by the following illustration:—If an exact model were made in ice of all the land above the level of the sea it would take twelve such models when melted to fill an ocean having the same superficial area as the land, and as the entire surface of the ocean as compared to that of the land is as two-and-a-half to one, it would be necessary to have thirty ice-models of the land above the sea-level in order to furnish sufficient water to fill the basin of our present oceans. Subaërial denudation would not of itself lessen the area of the land, but would tend to fill up with sediment seas of moderate depth adjoining the coast. The coarser matter falls to the bottom near the shore in the first still-water which it reaches, and whenever the sea-bottom on which this matter has been thrown is slightly elevated, it becomes land, and an upheaval of a thousand feet causes it to attain the mean elevation of continents in general.

Suppose, therefore, we had ascertained that the triturating power of subaërial denudation might in a given time—in three, or six, or a greater number of millions of years—pulverise a volume of rock equal in dimensions to all the present land, we might yet find, could we revisit the earth at the end of such a period, that the continents occupied very much the same position which they held before; we should find the rivers employed in carrying down to the sea the very same mud, sand, and pebbles with which they had been charged in our own time, the superficial alluvial matter as well as a great thickness of sedimentary strata would enclose shells, all or a great part of which we should recognise as specifically identical with those already known to us as living. Every geologist is aware that great as have been the geographical changes in the northern hemisphere since the commencement of the Glacial Period, there having been submergence and re-emergence of land to the extent of 1,000 feet vertically, and in the temperate latitudes great vicissitudes of climate, the marine mollusca have not changed, and the same drift which had been carried down to the sea at the beginning of the period is now undergoing a second transportation in the same direction.

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[1] Principles, vol. i. p. 269. 1872.

[2] Wyville Thomson, Depths of the Sea, p. 31. 1873.

As when we have measured a fraction of time in an hour-glass we have only to reverse the position of our chronometer and we make the same sand measure over again the duration of a second equal period, so when the volcanic force has remoulded the form of a continent and the adjoining sea-bottom, the same materials are made to do duty a second time. It is true that at each oscillation of level the solid rocks composing the original continent suffer some fresh denudation, and do not remain unimpaired like the wooden and glass framework of the hour-glass, still the wear and tear suffered by the larger area exposed to subaërial denudation consists either of loose drift or of sedimentary strata, which were thrown down in seas near the land, and subsequently upraised, the same continents and oceanic basins remaining in existence all the while.

From all that we know of the extreme slowness of the upward and downward movements which bring about even slight geographical changes, we may infer that it would require a long succession of geological periods to cause the submarine and supramarine areas to change places, even if the ascending movements in the one region and the descending in the other were continuously in one direction. But we have only to appeal to the structure of the Alps, where there are so many shallow and deep-water formations of various ages crowded into a limited area, to convince ourselves that mountain chains are the result of great oscillations of level. High land is not produced simply by uniform upheaval, but by a predominance of elevatory over subsiding movements. Where the ocean is extremely deep it is because the sinking of the bottom has been in excess, in spite of interruptions by upheaval.

Yet persistent as may be the leading features of land and sea on the globe, they are not immutable. Some of the finest mud is doubtless carried to indefinite distances from the coast by marine currents, and we are taught by deep-sea dredgings that in clear water at depths equalling the height of the Alps organic beings may flourish, and their spoils slowly accumulate on the bottom. We also occasionally obtain evidence that submarine volcanoes are pouring out ashes and streams of lava in mid-ocean as well as on land (see Principles, vol. ii. p. 64), and that wherever mountains like Etna, Vesuvius, and the Canary Islands are now the site of eruptions, there are signs of accompanying upheaval, by which beds of ashes full of recent marine shells have been uplifted many hundred feet. We need not be surprised, therefore, if we learn from geology that the continents and oceans were not always placed where they now are, although the imagination may well be overpowered when it endeavours to contemplate the quantity of time required for such revolutions.

We shall have gained a great step if we can approximate to the number of millions of years in which the average aqueous denudation going on upon the land would convey seaward a quantity of matter equal to the average volume of our continents, and this might give us a gauge of the minimum of volcanic force necessary to counteract such levelling power of running water; but to discover a relation between these great agencies and the rate at which species of organic beings vary, is at present wholly beyond the reach of our computation, though perhaps it may not prove eventually to transcend the powers of Man.

CHAPTER VIII.

CHRONOLOGICAL CLASSIFICATION OF ROCKS.

Aqueous, plutonic, volcanic, and metamorphic rocks considered chronologically—Terms Primary, Secondary, and Tertiary; Palæozoic, Mesozoic, and Cainozoic explained—On the different ages of the aqueous rocks—Three principal tests of relative age: superposition, mineral character, and fossils—Change of mineral character and fossils in the same continuous formation—Proofs that distinct species of animals and plants have lived at successive periods—Distinct provinces of indigenous species—Great extent of single provinces—Similar laws prevailed at successive geological periods—Relative importance of mineral and paleontological characters—Test of age by included fragments—Frequent absence of strata of intervening periods—Tabular views of fossiliferous strata.

Chronology of rocks.—In the first chapter it was stated that the four great classes of rocks, the aqueous, the volcanic, the plutonic, and the metamorphic, would each be considered not only in reference to their mineral characters, and mode of origin, but also to their relative age. In regard to the aqueous rocks, we have already seen that they are stratified, that some are calcareous, others argillaceous or siliceous, some made up of sand, others of pebbles; that some contain freshwater, others marine fossils, and so forth; but the student has still to learn which rocks, exhibiting some or all of these characters, have originated at one period of the earth's history, and which at another.

To determine this point in reference to the fossiliferous formations is more easy than in any other class, and it is therefore the most convenient and natural method to begin by establishing a chronology for these strata, and then to refer as far as possible to the same divisions, the several groups of plutonic, volcanic, and metamorphic rocks. Such a system of classification is not only recommended by its greater clearness and facility of application, but is also best fitted to strike the imagination by bringing into one view the contemporaneous revolutions of the inorganic and organic creations of former times. For the sedimentary formations are most readily distinguished by the different species of fossil animals and plants which they inclose, and of which one set after another has flourished and then disappeared from the earth in succession.

In the present work, therefore, the four great classes of rocks, the aqueous, plutonic, volcanic, and metamorphic, will form four parallel, or nearly parallel, columns in one chronological table. They will be considered as four sets of monuments relating to four contemporaneous, or nearly contemporaneous, series of events. I shall endeavour, in a subsequent chapter on the plutonic rocks, to explain the manner in which certain masses belonging to each of the four classes of rocks may have originated simultaneously at every geological period, and how the earth's crust may have been continually remodelled, above and below, by aqueous and igneous causes, from times indefinitely remote. In the same manner as aqueous and fossiliferous strata are now formed in certain seas or lakes, while in other places volcanic rocks break out at the surface, and are connected with reservoirs of melted matter at vast depths in the bowels of the earth,—so, at every era of the past, fossiliferous deposits and superficial igneous rocks were in progress contemporaneously with others of subterranean and plutonic origin, and some sedimentary strata were exposed to heat, and made to assume a crystalline or metamorphic structure.

It can by no means be taken for granted, that during all these changes the solid crust of the earth has been increasing in thickness. It has been shown, that so far as aqueous action is concerned, the gain by fresh deposits, and the loss by denudation, must at each period have been equal (see above, p. 73) ; and in like manner, in the inferior portion of the earth's crust, the acquisition of new crystalline rocks, at each successive era, may merely have counterbalanced the loss sustained by the melting of materials previously consolidated. As to the relative antiquity of the crystalline foundations of the earth's crust, when compared to the fossiliferous and volcanic rocks which they support, I have already stated, in the first chapter, that to pronounce an opinion on this matter is as difficult as at once to decide which of the two, whether the foundations or superstructure of an ancient city built on wooden piles, may be the oldest. We have seen that, to answer this question, we must first be prepared to say whether the work of decay and restoration had gone on most rapidly above or below ; whether the average duration of the piles has exceeded that of the buildings, or the contrary. So also in regard to the relative age of the superior and inferior portions of the earth's crust ; we cannot hazard even a conjecture on this point, until we know whether, upon an average, the power of water above, or that of heat below, is most efficacious in giving new forms to solid matter.

The early geologists gave to all the crystalline and non-fossiliferous rocks the name of primitive or Primary, under the idea that they were formed anterior to the appearance of life upon the earth, while the aqueous or fossiliferous strata were termed Secondary, and alluviums or other superficial deposits, Tertiary. The meaning of these terms has, however, been gradually modified with advancing knowledge, and they are now used to designate three great chronological divisions under which all geological formations can be classed, each of them being characterised by the presence of distinctive groups of organic remains rather than by any mechanical peculiarities of the strata themselves. If, therefore, we retain the term 'primary,' it must not be held to designate a set of crystalline rocks some of which have been proved to be even of Tertiary age, but must be applied to all rocks older than the secondary formations. Some geologists, to avoid misapprehension, have introduced the term Palæozoic for primary, from παλαιον, 'ancient,' and ζωον, 'an organic being,' still retaining the terms secondary and tertiary; Professor Phillips, for the sake of uniformity, has proposed Mesozoic, for secondary, from μεσος, 'middle,' &c.; and Cainozoic, for tertiary, from καινος, 'recent,' &c.; but the terms primary, secondary, and tertiary have the claim of priority in their favour, and are of corresponding value.

It may perhaps be suggested that some metamorphic strata, and some granites, may be anterior in date to the oldest of the primary fossiliferous rocks. This opinion is doubtless true, and will be discussed in future chapters; but I may here observe, that when we arrange the four classes of rocks in four parallel columns in one table of chronology, it is by no means assumed that these columns are all of equal length; one may begin at an earlier period than the rest, and another may come down to a later point of time, and we may not be yet acquainted with the most ancient of the primary fossiliferous rocks, or with the newest of the hypogene or netherformed (see p. 10).

For reasons already stated, I proceed first to treat of the aqueous or fossiliferous formations considered in chronological order or in relation to the different periods at which they have been deposited.

There are three principal tests by which we determine the age of a given set of strata; first, superposition; secondly, mineral character; and, thirdly, organic remains. Some aid can occasionally be derived from a fourth kind of proof, namely, the fact of one deposit including in it fragments of a pre-existing rock, by which the relative ages of the two may, even in the absence of all other evidence, be determined.

Superposition.—The first and principal test of the age of one aqueous deposit, as compared to another, is relative position. It has been already stated, that, where strata are horizontal, the bed which lies uppermost is the newest of the whole, and that which lies at the bottom the most ancient. So, of a series of sedimentary formations, they are like volumes of history, in which each writer has recorded the annals of his own times, and then laid down the book, with the last written page uppermost, upon the volume in which the events of the era immediately preceding were commemorated. In this manner a lofty pile of chronicles is at length accumulated; and they are so arranged as to indicate, by their position alone, the order in which the events recorded in them have occurred.

In regard to the crust of the earth, however, there are some regions where, as the student has already been informed, the beds have been disturbed, and sometimes extensively thrown over and turned upside down. (See pp. 50, 64.) But an experienced geologist can rarely be deceived by these exceptional cases. When he finds that the strata are fractured, curved, inclined, or vertical, he knows that the original order of superposition must be doubtful, and he then endeavours to find sections in some neighbouring district where the strata are horizontal, or only slightly inclined. Here, the true order of sequence of the entire series of deposits being ascertained, a key is furnished for settling the chronology of those strata where the displacement is extreme.

Mineral character.—The same rocks may often be observed to retain for miles, or even hundreds of miles, the same mineral peculiarities, if we follow the planes of stratification, or trace the beds, if they be undisturbed, in a horizontal direction. But if we pursue them vertically, or in any direction transverse to the planes of stratification, this uniformity ceases almost immediately. In that case we can scarcely ever penetrate a stratified mass for a few hundred yards without beholding a succession of extremely dissimilar rocks, some of fine, others of coarse grain, some of mechanical, others of chemical origin; some calcareous, others argillaceous, and others siliceous. These phenomena lead to the conclusion, that rivers and currents have dispersed the same sediment over wide areas at one period, but at successive periods have been charged, in the same region, with very different kinds of matter. The first observers were so astonished at the vast spaces over which they were able to follow the same homogeneous rocks in a horizontal direction, that they came hastily to the opinion, that the whole globe had been environed by a succession of distinct aqueous formations, disposed round the nucleus of the planet, like the concentric coats of an onion. But, although, in fact, some formations may be continuous over districts as large as half of Europe, or even more, yet most of them either terminate wholly within narrower limits, or soon change their lithological character. Sometimes they thin out gradually, as if the supply of sediment had failed in that direction, or they come abruptly to an end, as if we had arrived at the borders of the ancient sea or lake which served as their receptacle. It no less frequently happens that they vary in mineral aspect and composition, as we pursue them horizontally. For example, we trace a limestone for a hundred miles, until it becomes more arenaceous, and finally passes into sand, or sandstone. We may then follow this sandstone, already proved by its continuity to be of the same age, throughout another district a hundred miles or more in length.

Organic remains.—This character must be used as a test of the age of a formation or of the contemporaneous origin of two deposits in distant places, under very much the same restrictions as the test of mineral composition.

First, the same fossils may be traced over wide regions, if we examine strata in the direction of their planes, although by no means for indefinite distances. Secondly, while the same fossils prevail in a particular set of strata for hundreds of miles in a horizontal direction, we seldom meet with the same remains for many fathoms, and very rarely for several hundred yards, in a vertical direction, or a direction transverse to the strata. This fact has now been verified in almost all parts of the globe, and has led to a conviction, that at successive periods of the past, the same area of land and water has been inhabited by species of animals and plants even more distinct than those which now people the antipodes, or which now co-exist in the arctic, temperate, and tropical zones. It appears, that from the remotest periods there has been ever a coming in of new organic forms, and an extinction of those which pre-existed on the earth; some species have endured for a longer, others for a shorter, time; while none have ever re-appeared after once dying out. The law which has governed the succession of species, whether we adopt or reject the theory of transmutation, seems to be expressed in the verse of the poet,—

Natura il fece, e poi ruppe la stampa. ARIOSTO.
Nature made him, and then broke the die.

And this circumstance it is, which confers on fossils their highest value as chronological tests, giving to each of them, in the eyes of the geologist, that authority which belongs to contemporary medals in history.

The same cannot be said of each peculiar variety of rock; for some of these, as red marl and red sandstone, for example, may occur at once at the top, bottom, and middle of the entire sedimentary series; exhibiting in each position so perfect an identity of mineral aspect as to be undistinguishable. Such exact repetitions, however, of the same mixtures of sediment have not often been produced, at distant periods, in precisely the same parts of the globe; and even where this has happened, we are not in any danger of confounding together the monuments of remote eras, when we have studied their imbedded fossils and their relative position.

Zoological provinces.—It was remarked that the same species of organic remains cannot be traced horizontally, or in the direction of the planes of stratification for indefinite distances. This might have been expected from analogy; for when we enquire into the present distribution of living beings we find that the habitable surface of the sea and land may be divided into a considerable number of distinct areas or provinces, each peopled by a peculiar assemblage of animals and plants. In the Principles of Geology, I have endeavoured to point out the extent and probable origin of these separate divisions; and it was shown that climate is only one of many causes on which they depend, and that difference of longitude as well as latitude is generally accompanied by a dissimilarity of indigenous species.

As different seas, therefore, and lakes are inhabited, at the same period in different zones and depths, by different aquatic animals and plants, and as the lands adjoining these may be peopled by distinct terrestrial species, it follows that distinct fossils will be imbedded in contemporaneous deposits. If it were otherwise—if the same species abounded in every climate, or in every part of the globe where, so far as we can discover, a corresponding temperature and other conditions favourable to their existence are found—the identification of mineral masses of the same age, by means of their included organic contents, would be a matter of still greater certainty.

Nevertheless, the extent of some single zoological provinces, especially those of marine animals, is very great; and our geological researches have proved that the same laws prevailed at remote periods; for the fossils are often identical throughout wide spaces, and in detached deposits, consisting of rocks, varying entirely in their mineral nature.

The doctrine here laid down will be more readily understood, if we reflect on what is now going on in the Mediterranean. That entire sea may be considered as one zoological province; for although certain species of testacea and zoophytes may be very local, and each region, according to its depth, the temperature and saltness of the water and other conditions, has probably some species peculiar to it, still a considerable number are common to the whole Mediterranean. If, therefore, at some future period, the bed of this inland sea should be converted into land, the geologist might be enabled, by reference to organic remains, to prove the contemporaneous origin of various mineral masses scattered over a space equal in area to half of Europe.

Deposits, for example, are well known to be now in progress in this sea in the deltas of the Po, Rhone, Nile, and other rivers, which differ as greatly from each other in the nature of their sediment as does the composition of the mountains which they drain. There are also other quarters of the Mediterranean, as off the coast of Campania, or near the base of Etna, in Sicily, or in the Grecian Archipelago, where another class of rocks is now forming; where showers of volcanic ashes occasionally fall into the sea, and streams of lava overflow its bottom; and where, in the intervals between volcanic eruptions, beds of sand and clay are frequently derived from the waste of cliffs, or the turbid waters of rivers. Limestones, moreover, such as the Italian travertins, are here and there precipitated from the waters of mineral springs, some of which rise up from the bottom of the sea. In all these detached formations, so diversified in their lithological characters, the remains of the same shells, corals, crustacea, and fish are becoming enclosed; or, at least, a sufficient number must be common to the different localities to enable the zoologist to refer them all to one contemporaneous assemblage of species.

There are, however, certain combinations of geographical circumstances which cause distinct provinces of animals and plants to be separated from each other by very narrow limits; and hence it must happen that strata will be sometimes formed in contiguous regions, differing widely both in mineral contents and organic remains. Thus, for example, the testacea, zoophytes, and fish of the Red Sea are, as a group, extremely distinct from those inhabiting the adjoining parts of the Mediterranean, the narrow isthmus of Suez (which until the opening of the canal in the last few years separated the two seas) having acted as an efficient barrier. Calcareous formations have accumulated on a great scale in the Red Sea in modern times, and fossil shells of existing species are well preserved therein; and we know that at the mouth of the Nile large deposits of mud are amassed, including the remains of Mediterranean species. It follows, therefore, that if at some future period the bed of the Red Sea should be laid dry, the geologist might experience great difficulties in endeavouring to ascertain the relative age of these formations, which, although dissimilar both in organic and mineral characters, were of synchronous origin.

But, on the other hand, we must not forget that the north-western shores of the Arabian Gulf, the plains of Egypt, and the Isthmus of Suez, are all parts of one province of *terrestrial* species. Small streams, therefore, occasional land-floods, and those winds which drift clouds of sand along the deserts might carry down into the Red Sea the same shells of fluviatile and land testacea which the Nile is sweeping into its delta, together with some remains of terrestrial plants and the bones of quadrupeds, whereby the groups of strata, before alluded to, might, notwithstanding the discrepancy of their mineral composition and *marine* organic fossils, be shown to have belonged to the same epoch.

Yet while rivers may thus carry down the same fluviatile and terrestrial spoils into two or more seas inhabited by different marine species, it will much more frequently happen, that the co-existence of terrestrial species of distinct zoological and botanical provinces will be proved by the identity of the marine beings which inhabited the intervening space. Thus, for example, the land quadrupeds and shells of the valley of the Mississippi, of Central America, and of the West India Islands differ very considerably, yet their remains are all washed down by rivers flowing from these three zoological provinces into the Gulf of Mexico.

In some parts of the globe, at the present period, the line of demarcation between distinct provinces of animals and plants is not very strongly marked, especially where the change is determined by temperature, as it is in seas extending from the temperate to the tropical zone, or from the temperate to the arctic regions. Here a gradual passage takes place from one set of species to another. In like manner the geologist, in studying particular formations of remote periods, has sometimes been able to trace the gradation from one ancient province to another, by observing carefully the fossils of all the intermediate places. His success in thus acquiring a knowledge of the zoological or botanical geography of very distant eras has been mainly owing to this circumstance, that the mineral character has no tendency to be affected by climate. A large river may convey yellow or red mud into some part of the ocean, where it may be dispersed by a current over an area several hundred leagues in length, so as to pass from the tropics into the temperate zone. If the bottom of the sea be afterwards upraised, the organic remains imbedded in such yellow or red strata may indicate the different animals or plants which once inhabited at the same time the temperate and equatorial regions.

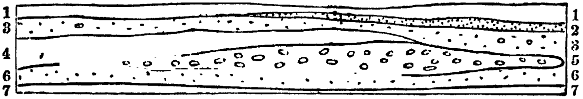
It may be true, as a general rule, that groups of the same species of animals and plants may extend over wider areas than deposits of homogeneous composition; and if so, paleontological characters will be of more importance in geological classification than the test of mineral composition; but it is idle to discuss the relative value of these tests, as the aid of both is indispensable, and it fortunately happens, that where the one criterion fails, we can often avail ourselves of the other.

Test by included fragments of older rocks.—It was stated that proof may sometimes be obtained of the relative date of two formations, by fragments of an older rock being included in a newer one. This evidence may sometimes be of great use, where a geologist is at a loss to determine the relative age of two formations from want of clear sections exhibiting their true order of position, or because the strata of each group are vertical. In such cases we sometimes discover that the more modern rock has been in part derived from the degradation of the older. Thus, for example, we may find chalk in one part of a country, and in another strata of clay, sand, and pebbles. If some of these pebbles consist of that peculiar flint, of which layers more or less continuous are characteristic of the chalk, and which include fossil shells, sponges, and foraminifera of cretaceous species, we may confidently infer that the chalk was the oldest of the two formations.

Chronological groups.—The number of groups into which the fossiliferous strata may be separated are more or less numerous, according to the views of classification which different geologists entertain; but when we have adopted a certain system of arrangement, we immediately find that a few only of the entire series of groups occur one upon the other in any single section or district.

The thinning out of individual strata was before described (p. 17). But let the annexed diagram represent seven fossiliferous groups, instead of as many strata. It will then be seen that in the middle all the superimposed formations are present; but in consequence of some of them thinning out, No. 2 and

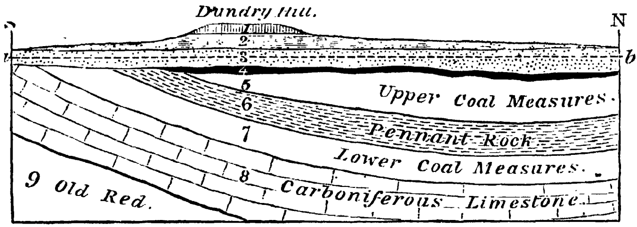
Fig. 84.



No. 5 are absent at one extremity of the section, and No. 4 at the other.

In another diagram, fig. 85, a true section of the geological formations in the neighbourhood of Bristol and the Mendip Hills is presented to the reader, as laid down on a natural scale by Professor Ramsay, where the newer groups 1, 2, 3, 4 rest unconformably on the formations 5, 6, 7, and 8. At the southern end of the line of section we meet with the beds No. 3 (the New Red Sandstone) resting immediately on Nos. 7 and 8, while farther north, as at Dundry Hill in Somersetshire, we have eight groups superimposed one upon the other, comprising all the strata from the inferior oolite, No. 1, to the coal and carboniferous limestone. The limited horizontal extension of the groups 1 and 2 is owing to subsequent denudation, as these formations end abruptly, and have left outlying patches to attest the fact of their having originally covered a much wider area.

Fig. 85.



Section South of Bristol. (A. C. Ramsay.)

Length of section 4 miles. *a*, *b*. Level of the sea.

1. Inferior Oolite. 2. Lias. 3. New Red Sandstone. 4. Dolomitic or magnesian conglomerate. 5. Upper coal measures (shales, &c.). 6. Pennant rock (sandstone). 7. Lower coal measures (shales, &c.). 8. Carboniferous or mountain limestone. 9. Old red sandstone.

In order, therefore, to establish a chronological succession of fossiliferous groups, a geologist must begin with a single section in which several sets of strata lie one upon the other. He must then trace these formations, by attention to their mineral character and fossils, continuously as far as possible, from the starting point. As often as he meets with new groups, he must ascertain by superposition their age relatively to those first examined, and thus learn how to intercalate them in a tabular arrangement of the whole.

By this means the German, French, and English geologists have determined the succession of strata throughout the greater part of Europe, and have adopted pretty generally the following groups, almost all of which have their representatives in the British Islands.

ABRIDGED GENERAL TABLE OF FOSSILIFEROUS STRATA.

1.	RECENT.		**POST-TERTIARY.**	TERTIARY or CAINOZOIC.	NEOZOIC.
2.	PLEISTOCENE.				
3.	NEWER PLIOCENE.		**PLIOCENE.**		
4.	OLDER PLIOCENE.				
5.	UPPER MIOCENE.		**MIOCENE.**		
6.	LOWER MIOCENE.				
7.	UPPER EOCENE.		**EOCENE.**		
8.	MIDDLE EOCENE.				
9.	LOWER EOCENE.				
10.	MAESTRICHT BEDS.		**CRETACEOUS.**	SECONDARY or MESOZOIC.	
11.	WHITE CHALK.				
12.	CHLORITIC SERIES.				
13.	GAULT.				
14.	NEOCOMIAN.				
15.	WEALDEN.				
16.	PURBECK BEDS.		**JURASSIC.**		
17.	PORTLAND STONE.				
18.	KIMMERIDGE CLAY.				
19.	CORAL RAG.				
20.	OXFORD CLAY.				
21.	GREAT or BATH OOLITE.				
22.	INFERIOR OOLITE.				
23.	LIAS.				
24.	UPPER TRIAS.		**TRIASSIC.**		
25.	MIDDLE TRIAS.				
26.	LOWER TRIAS.				
27.	PERMIAN.		**PERMIAN.**	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
28.	COAL-MEASURES.		**CARBONIFEROUS.**		
29.	CARBONIFEROUS LIMESTONE.				
30.	UPPER	DEVONIAN.	**DEVONIAN.**		
31.	MIDDLE				
32.	LOWER				
33.	UPPER	SILURIAN.	**SILURIAN.**		
34.	LOWER				
35.	UPPER	CAMBRIAN.	**CAMBRIAN.**		
36.	LOWER				
37.	UPPER	LAURENTIAN.	**LAURENTIAN.**		
38.	LOWER				

TABULAR VIEW
OF
THE FOSSILIFEROUS STRATA,

SHOWING THE ORDER OF SUPERPOSITION OR CHRONOLOGICAL SUCCESSION OF THE PRINCIPAL GROUPS, WITH REFERENCE TO THE PAGES WHERE THEY ARE DESCRIBED IN THIS WORK.

POST-TERTIARY.

		EXAMPLES.
POST-TERTIARY	1 **RECENT** Shells and mammalia, all of living species.	*British*—Clyde marine strata, with canoes (p. 123). *Foreign*—Danish Kitchen Middens (p. 124). Lacustrine mud, with remains of Swiss lake-dwellings (p. 125). Marine strata inclosing Temple of Serapis, at Puzzuoli (p. 123).
	2 **PLEISTOCENE** Shells recent, mammalia in part extinct.	*British*—Loam of Brixham cave, with flint implements and bones of extinct and living quadrupeds (p. 135). Drift near Salisbury with bones of mammoth, Spermophilus, and stone implements (p. 139). Glacial drift of Scotland, with marine shells and remains of mammoth (p. 155). Erratics of Pagham and Selsea Bill (p. 162). Glacial drift of Wales with marine fossil shells about 1,400 feet high, on Moel Tryfaen (p. 160). *Foreign*—Dordogne caves of the reindeer period (p. 127). Older Valley-gravels of Amiens, with flint implements and bones of extinct mammalia (p. 129). Loess of Rhine (p. 131). Ancient Nile-mud forming river-terraces (p. 132). Loam and breccia of Liége caverns, with human remains (p. 134). Australian cave breccias, with bones of extinct marsupials (p. 136). Glacial drift of Northern Europe (pp. 144-168).

TERTIARY OR CAINOZOIC.

PLIOCENE	3 **NEWER PLIOCENE** The shells almost all of living species.	*British*—Bridlington beds, marine Arctic fauna (p. 169). Glacial boulder formation of Norfolk cliffs (p. 170). Forest-bed of Norfolk cliffs, with bones of *Elephas meridionalis*, &c. (p. 172). Chillesford and Aldeby beds, with marine shells, chiefly Arctic (p. 172). Norwich crag (p. 173). *Foreign*—Eastern base of Mount Etna, with marine shells (p. 186). Sicilian calcareous and tufaceous strata (p. 187). Lacustrine strata of Upper Val d'Arno (p. 189). Madeira leaf-bed and land-shells (p. 532).
	4 **OLDER PLIOCENE** Extinct species of shells forming a large minority.	*British*—Red crag of Suffolk, marine shells, some of northern forms (p. 175). White or coralline crag of Suffolk (p. 178). *Foreign*—Antwerp crag (p. 185). Subapennine marls and sands (p. 189).

		Examples.
MIOCENE	**5** **UPPER MIOCENE** Majority of the shells extinct.	*British*—Wanting. *Foreign*—Faluns of Touraine (p. 192). Faluns, proper, of Bordeaux (p. 195). Freshwater strata of Gers (p. 196). Swiss Œningen beds, rich in plants and insects (pp. 197–206). Marine molasse, Switzerland (p. 206). Bolderberg beds of Belgium (p. 206). Vienna basin (p. 207). Beds of the Superga, near Turin (p. 208). Deposit at Pikermi, near Athens (p. 208). Strata of the Siwâlik hills, India (p. 209). Marine strata of the Atlantic border in the United States (p. 210). Volcanic tuff and limestone of Madeira, the Canaries, and the Azores (Chap. XXX).
	6 **LOWER MIOCENE** Nearly all the shells extinct.	*British*—Hempstead beds, marine and freshwater strata (p. 227). Lignites and clays of Bovey Tracey (p. 229). Isle of Mull leaf-bed, volcanic tuff (p. 230). *Foreign*—Calcaire de la Beauce, &c. (p. 213). Grès de Fontainebleau (p. 213). Lacustrine strata of the Limagne d'Auvergne, and the Cantal (p. 216). Mayence basin (p. 225). Radaboj beds of Croatia (p. 225). Brown coal of Germany (p. 227). Lower molasse of Switzerland, freshwater and brackish (pp. 218–222). Rupelmonde, Kleynspawen, and Tongrian beds of Belgium (p. 224). Nebraska beds, United States (p. 232). Lower Miocene beds of Italy (p. 227). Miocene flora of North Greenland (p. 222).
EOCENE	**7** **UPPER EOCENE**	*British*—Bembridge, fluvio-marine strata (p. 235). Osborne or St. Helen's series (p. 238). Headon series, with marine and freshwater shells (p. 238). Barton sands and clays (p. 241). *Foreign*—Gypsum of Montmartre, freshwater with *Paleotherium* (p. 254). Calcaire silicieux, or Travertin inférieur (p. 257). Grès de Beauchamp or Sables moyens (p. 257).
	8 **MIDDLE EOCENE**	*British*—Bracklesham beds and Bagshot sands (p. 243). White clays of Alum Bay and Bournemouth (p. 245). *Foreign*—Calcaire grossier, miliolitic limestone (p. 257). Soissonnais sands, or Lits coquilliers, with *Nummulites planulata* (p. 259). Claiborne beds of United States, with *Orbitoides* and *Zeuglodon* (p. 262).
	9 **LOWER EOCENE**	Nummulitic formation of Europe, Asia, &c. (p. 260). *British*—London clay proper (p. 247). Woolwich and Reading series, fluvio-marine (p. 250). Thanet sands (p. 252). *Foreign*—Argile de Londres, near Dunkirk (p. 235). Argile plastique (p. 259). Sables de Bracheux (p. 260).

SECONDARY OR MESOZOIC.

CRETACEOUS	**10** **UPPER CRETACEOUS**	*British*—Upper white chalk, with flints (p. 269). Lower white chalk, without flints (p. 281). Chalk marl (p. 281). Chloritic series (or Upper Greensand), fire-stone of Surrey (p. 282). Gault (p. 284). Blackdown beds (p. 285).

		EXAMPLES.
CRETACEOUS	**10 UPPER CRETACEOUS**	*Foreign*—Maestricht beds and Faxoe chalk (pp. 266–269). Pisolitic limestone of France (p. 268). White chalk of France, Sweden, and Russia (p. 270). Pläner-kalk of Saxony (p. 276). Sands and clays of Aix-la-Chapelle (p. 285). Hippurite limestone of South of France (p. 288). New Jersey, U.S., sands and marls (p. 290).
	11 LOWER CRETACEOUS or NEOCOMIAN	*British*—Sands of Folkestone, Sandgate, Hythe, and the Isle of Wight (p. 292). Atherfield clay, with *Perna mulleti* (p. 293). Speeton clay of Flamborough Head, and Tealby sands and sandstones (p. 295). Punfield marine beds, with *Vicarya lujana* (p. 303). Weald clay of Surrey, Kent, and Sussex, freshwater, with *Cypris* (p. 298). Hastings sands (p. 300). *Foreign*—Neocomian of Neufchatel, and Hils conglomerate of North Germany (p. 297). Wealden beds of Hanover (p. 304).
OOLITE	**12 UPPER OOLITE**	*British*—Upper Purbeck beds, freshwater (p. 309). Middle Purbeck, with numerous marsupial quadrupeds, &c. (p. 310). Lower Purbeck, freshwater, with intercalated dirt-bed (p. 317). Portland stone and sand (p. 321). Kimmeridge clay (p. 323). *Foreign*—Marnes à gryphées virgules of Argonne (p. 323). Lithographic stone of Solenhofen, with *Archæopteryx* (p. 323).
	13 MIDDLE OOLITE	*British*—Coral rag of Berkshire, Wilts, and Yorkshire (p. 325). Oxford clay, with belemnites and ammonites (p. 327). Kelloway rock of Wilts and Yorkshire (p. 328). *Foreign*—Nerinæan limestone of the Jura (p. 326).
	14 LOWER OOLITE	*British*—Cornbrash and forest marble (p. 328). Great or Bath oolite of Bradford (p. 328). Stonesfield slate, with Marsupials and *Araucaria* (p. 332). Fuller's earth of Bath (p. 336). Inferior oolite (p. 336).
LIAS	**15 LIAS**	Upper lias, argillaceous, with *Ammonites striatulus* (p. 340). Shale and limestone, with *Ammonites bifrons* (p. 340). Middle lias or Marlstone series, with zones containing characteristic ammonites (p. 340). Lower lias, also with zones characterised by peculiar ammonites (p. 343).
TRIAS	**16 UPPER TRIAS**	*British*—Rhætic, Penarth or *Avicula contorta* beds (beds of passage) (p. 354). Keuper or Upper New Red sandstone, &c. (p. 357). Red shales of Cheshire and Lancashire, with rock-salt (p. 362). Dolomitic conglomerate of Bristol (p. 361). *Foreign*—Keuper beds of Germany (p. 365). St. Cassian or Hallstadt beds, with rich marine fauna (p. 365). Coalfield of Richmond, Virginia (p. 372). Chatham coalfield, North Carolina (p. 373).
	17 MIDDLE TRIAS	*British*—Wanting. *Foreign*—Muschelkalk of Germany (p. 368).
	18 LOWER TRIAS	*British*—Bunter or Lower New Red sandstone of Lancashire and Cheshire (p. 360). *Foreign*—Bunter-sandstein of Germany (p. 370). Red sandstone of Connecticut Valley, with footprints of birds and reptiles (p. 371).

PRIMARY OR PALÆOZOIC.

		EXAMPLES.
PERMIAN	19 PERMIAN	*British*—Upper Permian of St. Bees' Head and Corby, Cumberland (p. 376). Middle Permian, magnesian limestone, and marlslate of Durham and Yorkshire, with *Protorosaurus* (p. 376). Lower Permian sandstones and breccias of Penrith and Dumfriesshire, intercalated (p. 381). *Foreign*—Dark-coloured shales of Thuringia (p. 382). Zechstein or Dolomitic limestone (p. 382). Mergel-schiefer or Kupfer-schiefer (p. 382). Roth-liegendes of Thuringia, with *Psaronius* (p. 382). Magnesian limestones, &c., of Russia (p. 383).
CARBONIFEROUS	20 UPPER CARBONIFEROUS	*British*—Coal measures of South Wales, with underclays enclosing *Stigmaria* (p. 388). Coal measures of north and central England (p. 386). Millstone grit (p. 386). Yoredale series of Yorkshire (p. 386). Coalfield of Kilkenny, with *Labyrinthodont* (p. 400). *Foreign*—Coalfield of Saarbruck, with *Archegosaurus* (p. 397). Carboniferous strata of South Joggins, Nova Scotia (p. 401). Pennsylvanian coalfield (p. 391).
	21 LOWER CARBONIFEROUS	*British*—Mountain limestone of Wales and South of England (p. 425). Same in Ireland and carboniferous slate (p. 432). Carboniferous limestone of Scotland alternating with coal-bearing sandstones (p. 387). Erect trees in volcanic ash in the Island of Arran (p. 547). *Foreign*—Mountain limestone of Belgium (p. 431).
DEVONIAN or OLD RED SANDSTONE	22 UPPER DEVONIAN	*British*—Yellow sandstone of Dura Den, with *Holoptychius*, &c. (p. 436); and of Ireland with *Anodon Jukesii* (p. 436). Sandstones of Forfarshire and Perthshire, with *Holoptychius*, &c. (p. 437). Pilton group of North Devon (p. 446). Petherwyn group of Cornwall, with *Clymenia* and *Cypridina* (p. 447). *Foreign*—Clymenien-kalk and Cypridinen-schiefer of Germany (p. 449).
	23 MIDDLE DEVONIAN	*British*—Bituminous schists of Gamrie, Caithness, &c., with numerous fish (p. 438). Ilfracombe beds with peculiar trilobites and corals (p. 447). Limestones of Torquay, with numerous corals *Clymeniæ* and *Calceolæ* (p. 447). *Foreign*—Eifel limestone, with underlying schists containing *Calceola* (p. 449). Devonian strata of Russia (p. 451).
	24 LOWER DEVONIAN	*British*—Arbroath paving-stones, with *Cephalaspis* and *Pterygotus* (p. 442). Lower sandstones of Forfarshire, with *Pterygotus* (p. 442). Sandstones and slates of the Foreland and Linton (p. 450). *Foreign*—Oriskany sandstone of Western Canada and New York (p. 453). Sandstones of Gaspé, with *Cephalaspis* (p. 451).

		EXAMPLES.
SILURIAN	**25 UPPER SILURIAN**	*British*—Upper Ludlow formation, Downton sandstone, with bone-bed (p. 456). Lower Ludlow formation, with oldest known fish remains (p. 458). Wenlock limestone and shale (p. 462). Woolhope limestone and grit (p. 465). Tarannon shales (p. 466). Upper Llandovery, or May-hill sandstone, with *Pentamerus oblongus*, &c. (p. 466). Lower Llandovery slates (p. 468). Beds of passage between Upper and Lower Silurian. *Foreign*—Niagara limestone, with *Calymene, Homalonotus*, &c. (p. 478). Clinton group of America, with *Pentamerus oblongus*, &c. (p. 478). Silurian strata of Russia, with *Pentamerus* (p. 476).
	26 LOWER SILURIAN	*British*—Bala and Caradoc beds (p. 468). Llandeilo flags (p. 471). Arenig or Stiper-stones group (Lower Llandeilo of Murchison) (p. 474). *Foreign*—Ungulite or Obolus grit of Russia (p. 476). Trenton limestone, and other Lower Silurian groups of North America (p. 479). Lower Silurian of Sweden (p. 476). Lower Silurian of Bohemia (p. 477).
CAMBRIAN	**27 UPPER CAMBRIAN**	*British*—Tremadoc slates (p. 481). Lingula flags, with *Lingulella Davisii* (p. 483). *Foreign*—'Primordial' zone of Bohemia in part, with trilobites of the genera *Paradoxides*, &c. (p. 487). Alum schists of Sweden and Norway (p. 488). Potsdam sandstone, with *Dikelocephalus* and *Obolella* (p. 489).
	28 LOWER CAMBRIAN	*British*—Menevian beds of Wales, with *Paradoxides Davidis*, &c. (p. 484). Longmynd group, comprising the Harlech grits and Llanberis slates, and purple and green fossiliferous rock of St. David's (p. 485). *Foreign*—Lower portion of Barrande's 'Primordial' zone in Bohemia (p. 487). Fucoidal sandstones of Sweden (p. 488). Huronian series of Canada? (p. 489).
LAURENTIAN	**29 UPPER LAURENTIAN**	*British*—Fundamental gneiss of the Hebrides? (p. 492). Hypersthene rocks of Skye? (p. 490). *Foreign*—Labradorite series north of the river St. Lawrence in Canada (p. 490). Adirondack mountains of New York (p. 490).
	30 LOWER LAURENTIAN	*British*—Wanting? *Foreign*—Beds of gneiss and quartzite, with interstratified limestones, in one of which, 1,000 feet thick, occurs a foraminifer, *Eozoon Canadense*, the oldest known fossil (p. 491).

CHAPTER IX.

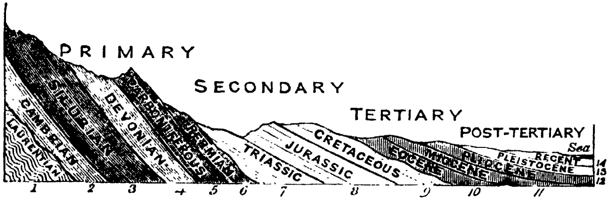
CLASSIFICATION OF TERTIARY FORMATIONS.

Order of succession of sedimentary formations—Frequent unconformability of strata—Imperfection of the record—Defectiveness of the monuments greater in proportion to their antiquity—Reasons for studying the newer groups first—Nomenclature of formations—Detached Tertiary formations scattered over Europe—Value of the shell-bearing mollusca in classification—Classification of Tertiary strata—Eocene, Miocene, and Pliocene terms explained.

By reference to the tables given at the end of the last chapter, the reader will see that when the fossiliferous rocks are arranged chronologically, we have first to consider the Post-tertiary and then the Tertiary or Cainozoic formations, and afterwards to pass on to those of older date.

Order of superposition.—The annexed diagram will show the order of superposition of these deposits, assuming them all to be visible in one continuous section. In nature, as before hinted, page 107, we have never an opportunity of seeing the whole of them so displayed in a single region; first, because sedimentary deposition is confined, during any one geological period, to limited areas; and secondly, because strata, after they have been formed, are liable to be utterly annihilated over wide areas by denudation. But wherever certain members of the series are present, they overlie one another in the *order* indicated in the diagram, though not always in the exact manner there represented, because some of them repose occasionally in unconformable stratification on others. This mode of superposition has been already explained at pp. 71, 88, where I

Fig. 86.



pointed out that the discordance which implies a considerable lapse of time between two formations in juxtaposition is almost invariably accompanied by a great dissimilarity in the species of organic remains.

Frequent unconformability of strata.—Where the widest gaps appear in the sequence of the fossil forms, as between the Permian and Triassic rocks, or between the Cretaceous and Eocene, examples of such unconformability are very frequent. But they are also met with in some part or other of the world at the junction of almost all the other principal formations, and sometimes the subordinate divisions of any one of the leading groups may be found lying unconformably on another subordinate member of the same—the Upper, for example, on the Lower Silurian, or the superior division of the Old Red Sandstone on a lower member of the same, and so forth. Instances of such irregularities in the mode of succession of the strata are the more intelligible the more we extend our survey of the fossiliferous formations, for we are continually bringing to light deposits of intermediate date, which have to be intercalated between those previously known, and which reveal to us a long series of events, of which antecedently to such discoveries we had no knowledge.

But while unconformability invariably bears testimony to a lapse of unrepresented time, the conformability of two sets of strata in contact by no means implies that the newer formation immediately succeeded the older one. It simply implies that the ancient rocks were subjected to no movements of such a nature as to tilt, bend, or break them before the more modern formation was superimposed. It does not show that the earth's crust was motionless in the region in question, for there may have been a gradual sinking or rising, extending uniformly over a large surface, and yet, during such movement, the stratified rocks may have retained their original horizontality of position. There may have been a conversion of a wide area from sea into land and from land into sea, and during these changes of level some strata may have been slowly removed by aqueous action, and after this new strata may be superimposed, differing perhaps in date by thousands of years or centuries, and yet resting conformably on the older set. There may even be a blending of the materials constituting the older deposit with those of the newer, so as to give rise to a passage in the mineral character of the one rock into the other as if there had been no break or interruption in the depositing process.

Imperfection of the record.—Although by the frequent discovery of new sets of intermediate strata the transition from one type of organic remains to another is becoming less and less abrupt, yet the entire series of records appears to the geologists now living far more fragmentary and defective than it seemed to their predecessors half a century ago. The earlier enquirers, as often as they encountered a break in the regular sequence of formations, connected it theoretically with a sudden and violent catastrophe, which had put an end to the regular course of events that had been going on uninterruptedly for ages, annihilating at the same time all or nearly all the organic beings which had previously flourished, after which, order being re-established, a new series of events was initiated. In proportion as our faith in these views grows weaker, and the phenomena of the organic or inorganic world presented to us by geology seem explicable on the hypothesis of gradual and insensible changes, varied only by occasional convulsions, on a scale comparable to that witnessed in historical times; and in proportion as it is thought possible that former fluctuations in the organic world may be due to the indefinite modifiability of species without the necessity of assuming new and independent acts of creation, the number and magnitude of the gaps which still remain, or the extreme imperfection of the record, become more and more striking, and what we possess of the ancient annals of the earth's history appears as nothing when contrasted with that which has been lost.

When we examine a large area such as Europe, the average as well as the extreme height above the sea attained by the older formations is usually found to exceed that reached by the more modern ones, the primary or palæozoic rising higher than the secondary, and these in their turn than the tertiary; while in reference to the three divisions of the tertiary, the lowest or Eocene group attains a higher summit level than the Miocene, and these again a greater height than the Pliocene formations. Lastly, the post-tertiary deposits, such, at least, as are of marine origin, are most commonly restricted to much more moderate elevations above the sea-level than the tertiary strata.

It is also observed that strata, in proportion as they are of newer date, bear the nearest resemblance in mineral character to those which are now in the progress of formation in seas or lakes, the newest of all consisting principally of soft mud or loose sand, in some places full of shells, corals, or other organic bodies, animal or vegetable, in others wholly devoid of such remains. The farther we recede from the present time, and the higher the antiquity of the formations which we examine, the greater are the changes which the sedimentary deposits have undergone. Time, as I have explained in Chapters V., VI. and VII., has multiplied the effects of condensation by pressure and cementation, and the modification produced by heat, fracture, contortion, upheaval and denudation. The organic remains also have sometimes been obliterated entirely, or the mineral matter of which they were composed has been removed and replaced by other substances.

Why newer groups should be studied first.—We likewise observe that the older the rocks the more widely do their organic remains depart from the types of the living creation. First, we find in the newer tertiary rocks a few species which no longer exist, mixed with many living ones, and then, as we go farther back, many genera and families at present unknown make their appearance, until we come to strata in which the fossil relics of existing species are nowhere to be detected, except a few of the lowest forms of invertebrata, while some orders of animals and plants wholly unrepresented in the living world begin to be conspicuous.

When we study, therefore, the geological records of the earth and its inhabitants, we find, as in human history, the defectiveness and obscurity of the monuments always increasing the remoter the era to which we refer, the rocks becoming more generally altered and crystalline the older they are, and the difficulty of determining their true chronological relations becoming more and more enhanced, especially when we are comparing those which were formed in very distant regions of the globe. Hence we advance with securer steps when we begin with the study of the geological records of later times, proceeding from the newer to the older, or from the more to the less known.

In thus inverting what might at first seem to be the more natural order of historical research, we must bear in mind that each of the periods above enumerated, even the shortest, such as the Post-tertiary, or the Pliocene, Miocene, or Eocene, embrace a succession of events of vast extent, so that to give a satisfactory account of what we already know of any one of them would require many volumes. When, therefore, we study *one of the newer groups* before endeavouring to decipher the monuments of an older one, it is like endeavouring to master the history of our own country and that of some contemporary nations, before we enter upon Roman History, or like investigating the annals of Ancient Italy and Greece before we approach those of Egypt and Assyria.

Nomenclature.—The origin of the terms Primary and Secondary, and the synonymous terms Palæozoic and Mesozoic, have been explained in the Eighth Chapter, p. 100.

The Tertiary or Cainozoic strata (see p. 100) were so called because they were all posterior in date to the Secondary series, of which last the Chalk or Cretaceous, No. 9, fig. 86, constitutes the newest group. The whole of them were at first confounded with the superficial alluviums of Europe ; and it was long before their real extent and thickness, and the various ages to which they belong, were fully recognised. They were observed to occur in patches, some of freshwater, others of marine origin, their geographical area being usually small as compared to the secondary formations, and their position often suggesting the idea of their having been deposited in different bays, lakes, estuaries, or inland seas, after a large portion of the space now occupied by Europe had already been converted into dry land.

The first deposits of this class, of which the characters were accurately determined, were those occurring in the neighbourhood of Paris, described in 1810 by MM. Cuvier and Brongniart. They were ascertained to consist of successive sets of strata, some of marine, others of freshwater origin, lying one upon the other. The fossil shells and corals were perceived to be almost all of unknown species, and to have in general a near affinity to those now inhabiting warmer seas. The bones and skeletons of land animals, some of them of large size, and belonging to more than forty distinct species, were examined by Cuvier, and declared by him not to agree specifically, nor most of them even generically, with any hitherto observed in the living creation.

Strata were soon afterwards brought to light in the vicinity of London, and in Hampshire, which, although dissimilar in mineral composition, were justly inferred by Mr. T. Webster to be of the same age as those of Paris, because the greater number of the fossil shells were specifically identical. For the same reason, rocks found in the Gironde, in the South of France, and at certain points in the North of Italy, were suspected to be of contemporaneous origin.

Another important discovery was soon afterwards made by Brocchi in Italy, who investigated the argillaceous and sandy deposits, replete with shells, which form a low range of hills flanking the Apennines on both sides, from the plains of the Po to Calabria. These lower hills were called by him the Subapennines, and were formed of strata chiefly marine, and newer than those of Paris and London.

Another tertiary group occurring in the neighbourhood of Bordeaux and Dax, in the South of France, was examined by M. de Basterot in 1825, who described and figured several hundred species of shells, which differed for the most part both from the Parisian series and those of the Subapennine hills. It was soon, therefore, suspected that this fauna might belong to a period intermediate between that of the Parisian and Subapennine strata, and it was not long before the evidence of superposition was brought to bear in support of this opinion; for other strata contemporaneous with those of Bordeaux were observed in one district (the Valley of the Loire) to overlie the Parisian formation, and in another (in Piedmont) to underlie the Subapennine beds. The first example of these was pointed out in 1829 by M. Desnoyers, who ascertained that the sand and marl of marine origin called Faluns, near Tours, in the basin of the Loire, full of seashells and corals, rested upon a lacustrine formation, which constitutes the uppermost subdivision of the Parisian group, extending continuously throughout a great table-land intervening between the basin of the Seine and that of the Loire. The other example occurs in Italy, where strata, containing many fossils similar to those of Bordeaux, were observed by Bonelli and others in the environs of Turin, subjacent to strata belonging to the Subapennine group of Brocchi.

Value of testacean fossils in classification.—It will be observed that in the foregoing allusions to organic remains, the testacea or the shell-bearing mollusca are selected as the most useful and convenient class for the purposes of general classification. In the first place, they are more universally distributed through strata of every age than any other organic bodies. Those families of fossils which are of rare and casual occurrence are absolutely of no avail in establishing a chronological arrangement. If we have plants alone in one group of strata and the bones of mammalia in another, we can draw no conclusion respecting the affinity or discordance of the organic beings of the two epochs compared; and the same may be said if we have plants and vertebrated animals in one series and only shells in another. Although corals are more abundant, in a fossil state, than plants, reptiles, or fish, they are still rare when contrasted with shells, because they are more dependent for their wellbeing on the constant clearness of the water, and are, therefore, less likely to be included in rocks which endure in consequence of their thickness and the copiousness of sediment which prevailed when they originated. The utility of the testacea is, moreover, enhanced by the circumstance that some forms are proper to the sea, others to the land, and others to freshwater. Rivers scarcely ever fail to carry down into their deltas some land-shells, together with species which are at once fluviatile and lacustrine. By this means we learn what terrestrial, freshwater, and marine species coexisted at particular eras of the past; and having thus identified strata formed in seas with others which originated contemporaneously in inland lakes, we are then enabled to advance a step farther, and show that certain quadrupeds or aquatic plants, found fossil in lacustrine formations, inhabited the globe at the same period when certain fish, reptiles, and zoophytes lived in the ocean.

Among other characters of the molluscous animals, which render them extremely valuable in settling chronological questions in geology, may be mentioned, first, the wide geographical range of many species ; and, secondly, what is probably a consequence of the former, the great duration in time of species in this class, for they appear to have surpassed in longevity the greater number of the fish and mammalia. Had each species inhabited a very limited space, it could never when imbedded in strata have enabled the geologist to identify deposits at distant points over large areas ; or had they each lasted but for a brief period, they could have thrown no light on the connection of rocks placed far from each other in the chronological, or, as it is often termed, vertical series.

Classification of Tertiary strata.—Many authors have divided the European Tertiary strata into three groups—lower, middle, and upper ; the lower comprising the oldest formations of Paris and London before mentioned ; the middle those of Bordeaux and Touraine in France, and mostly wanting in England ; and the upper all those newer than the middle group, comprising in England the crags of Norfolk and Suffolk.

In the first edition of the Principles of Geology I divided the whole of the Tertiary formations into four groups, characterised by the percentage of recent shells which they contained. The lower tertiary strata of London and Paris were thought by M. Deshayes to contain only 3½ per cent. of recent species, and were termed Eocene. The middle tertiary of the Loire and Gironde had, according to the specific determinations of the same eminent conchologist, 17 per cent., and formed the Miocene division. The Subapennine beds contained 35 to 50 per cent., and were termed Older Pliocene, while still more recent beds in Sicily, which had from 90 to 95 per cent. of species identical with those now living, were called Newer Pliocene. The first of the above terms, Eocene, is derived from ηως, eos, *dawn*, and καινος, cainos, *recent*, because the fossil shells of this period contain an extremely small proportion of living species, which may be looked upon as indicating the dawn of the existing state of the testaceous fauna, no recent species (with one or two exceptions) having been detected in the older or secondary rocks.

The term Miocene (from μειον, meion, *less*, and καινος, cainos, *recent*) is intended to express a minor proportion of recent species (of testacea), the term Pliocene (from πλειον, pleion, *more*, and καινος, cainos, *recent*) a comparative plurality of the same. It may assist the memory of students to remind them, that the *Mi*ocene contain a *mi*nor proportion, and *Pl*iocene, a comparative *pl*urality of recent species; and that the greater number of recent species always implies the more modern origin of the strata.

It has sometimes been objected to this nomenclature that certain species of infusoria found in the chalk are still existing, and, on the other hand, the Miocene and Older Pliocene deposits often contain the remains of mammalia, reptiles, and fish, exclusively of extinct species. But the reader must bear in mind that the terms Eocene, Miocene, and Pliocene were originally invented with reference purely to conchological data, and in that sense have always been, and are still used by me.

Since the year 1830 the number of known shells, both recent and fossil, has largely increased, and their identification has been more accurately determined. Hence some modifications have been required in the classifications founded on less perfect materials. The Eocene, Miocene, and Pliocene periods have been made to comprehend certain sets of strata of which the fossils do not always conform strictly in the numerical proportion of recent to extinct species with the definitions first given by me, or which are implied in the etymology of those terms.

CHAPTER X.

RECENT AND PLEISTOCENE PERIODS.

Recent and Pleistocene periods—Terms defined—Formations of the Recent Period—Modern littoral deposits containing works of art near Naples—Danish peat and shell mounds—Swiss lake-dwellings—Periods of stone, bronze, and iron—Pleistocene formations—Coexistence of man with extinct mammalia—Reindeer period of South of France—Alluvial deposits of Paleolithic age—Higher and Lower-level Valley-gravels—Loess or inundation mud of the Nile, Rhine, &c.—Origin of caverns—Remains of man and extinct quadrupeds in cavern deposits—Cave of Kirkdale—Australian cave-breccias—Geographical relationship of the provinces of living vertebrata and those of extinct Pleistocene species—Extinct struthious birds of New Zealand—Climate of the Pleistocene period—Comparative longevity of species in the mammalia and testacea—Teeth of Recent and Pleistocene mammalia.

We have seen in the last chapter that the uppermost or newest strata are called Post-tertiary, as being more modern than the Tertiary. It will also be observed that the Post-tertiary formations are divided into two subordinate groups : the Recent, and Pleistocene. In the former, or the Recent, the mammalia as well as the shells are identical with species now living ; whereas in the Pleistocene, the shells being all of living forms, a part, and often a considerable part, of the mammalia belong to extinct species. In former editions of this work I divided the Post-tertiary deposits into Recent and Post-pliocene, but this latter term has many inconveniences, especially that of often being confounded with Post-tertiary. I have, therefore, determined for the future to adopt the name of 'Pleistocene,' proposed by me in 1839 as a synonym for Newer Pliocene, but which having been used by the late Edward Forbes as the equivalent of Post-pliocene, has now passed into general use with that signification. In this volume the term 'Pleistocene' will accordingly be used for the lower subdivision of the Post-tertiary, and I shall only sometimes retain in a parenthesis the word Post-pliocene, to remind the reader that Pleistocene is used as its synonym.

Cases will occur where it may be scarcely possible to draw the boundary line between the Recent and Pleistocene (Post-pliocene) deposits ; and we must expect these difficulties to increase rather than diminish with every advance in our knowledge, and in proportion as gaps are filled up in the series of records.

RECENT PERIOD.

It was stated in the sixth chapter, when I treated of denudation, that the dry land, or that part of the earth's surface which is not covered by the waters of lakes or seas, is generally wasting away by the incessant action of rain and rivers, and in some cases by the undermining and removing power of waves and tides on the sea-coast. But the rate of waste is very unequal, since the level and gently sloping lands, where they are protected by a continuous covering of vegetation, escape nearly all wear and tear, so that they may remain for ages in a stationary condition, while the removal of matter is constantly widening and deepening the intervening ravines and valleys.

The materials, both fine and coarse, carried down annually by rivers from the higher regions to the lower, and deposited in successive strata in the basins of seas and lakes, must be of enormous volume. We are always liable to underrate their magnitude, because the accumulation of strata is going on out of sight.

There are, however, causes at work which, in the course of centuries, tend to render visible these modern formations, whether of marine or lacustrine origin. For a large portion of the earth's crust is always undergoing a change of level, some areas rising and others sinking at the rate of a few inches, or a few feet, perhaps sometimes yards, in a century, so that spaces which were once subaqueous are gradually converted into land, and others which were high and dry become submerged. In consequence of such movements we find in certain regions, as in Cashmere for example, where the mountains are often shaken by earthquakes, deposits which were formed in lakes in the historical period, but through which rivers have now cut deep and wide channels. In lacustrine strata thus intersected, works of art and freshwater shells are seen. In other districts on the borders of the sea, usually at very moderate elevations above its level, raised beaches occur, or marine littoral deposits, such as those in which, on the borders of the Bay of Baiæ, near Naples, the well-known temple of Serapis was imbedded. In that case the date of the monument buried in the marine strata is ascertainable, but in many other instances, the exact age of the remains of human workmanship is uncertain, as in the estuary of the Clyde at Glasgow, where many canoes have been exhumed, with other works of art, all assignable to some part of the Recent Period.

Danish peat and shell mounds or kitchen-middens.—Sometimes we obtain evidence, without the aid of a change of level, of events which took place in pre-historic times. The combined labours, for example, of the antiquary, zoologist, and botanist have brought to light many monuments of the early inhabitants buried in peat mosses in Denmark. Their geological age is determined by the fact that, not only the contemporaneous freshwater and land shells, but all the quadrupeds, found in the peat, agree specifically with those now inhabiting the same districts, or which are known to have been indigenous in Denmark within the memory of man. In the lower beds of peat (a deposit varying from 20 to 30 feet in thickness), weapons of stone accompany trunks of the Scotch fir, *Pinus sylvestris*. This peat may be referred to that part of the stone period for which Sir John Lubbock proposed the name of 'Neolithic'[1] in contradistinction to a still older era, termed by him 'Paleolithic,' and which will be described in the sequel. In the higher portions of the same Danish bogs, bronze implements are associated with trunks and acorns of the common oak. It appears that the pine has never been a native of Denmark in historical times, and it seems to have given place to the oak about the time when articles and instruments of bronze superseded those of stone. It also appears that, at a still later period, the oak itself became scarce, and was nearly supplanted by the beech, a tree which now flourishes luxuriantly in Denmark. Again, at the still later epoch when the beech tree abounded, tools of iron were introduced, and were gradually substituted for those of bronze.

On the coasts of the Danish islands in the Baltic, certain mounds, called in those countries 'Kjökken-mödding,' or 'kitchen-middens,' occur, consisting chiefly of the castaway shells of the oyster, cockle, periwinkle, and other eatable kinds of mollusks. The mounds are from 3 to 10 feet high, and from 100 to 1,000 feet in their longest diameter. They greatly resemble heaps of shells formed by the Red Indians of North America along the eastern shores of the United States, which I saw in 1845, and have described elsewhere.[2] In the old refuse-heaps, recently studied by the Danish antiquaries and naturalists with great skill and diligence, no implements of metal have ever been detected. All the knives, hatchets, and other tools, are of stone, horn, bone, or wood. With them are often intermixed fragments of rude pottery, charcoal and cinders, and the bones of quadrupeds on which the rude people fed. These bones belong to wild species still living in Europe, though some of them, like the beaver, have long been extirpated in Denmark. The only animal which they seem to have domesticated was the dog.

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[1] Sir John Lubbock, Prehistoric Times, p. 3. 1865.

[2] Second Visit to United States, vol. i. p. 338. 1845.

As there is an entire absence of metallic tools, these refuse-heaps are referred to the Neolithic division of the age of stone, which immediately preceded in Denmark the age of bronze. It appears that a race more advanced in civilisation, armed with weapons of that mixed metal, invaded Scandinavia, and ousted the aborigines.

Lacustrine habitations of Switzerland.—In Switzerland a different class of monuments, illustrating the successive ages of stone, bronze, and iron, has been of late years investigated with great success, and especially since 1854, in which year Dr. F. Keller explored near the shore at Meilen, in the bottom of the lake of Zurich, the ruins of an old village, originally built on numerous wooden piles, driven, at some unknown period, into the muddy bed of the lake. Since then a great many other localities, more than a hundred and fifty in all, have been detected of similar pile-dwellings, situated near the borders of the Swiss lakes, at points where the depth of water does not exceed 15 feet.[1] The superficial mud in such cases is filled with various articles, many hundreds of them being often dredged up from a very limited area. Thousands of piles, decayed at their upper extremities, are often met with still firmly fixed in the mud.

As the ages of stone, bronze, and iron merely indicate successive stages of civilisation, they may all have coexisted at once in different parts of the globe, and even in contiguous regions, among nations having little intercourse with each other. To make out, therefore, a distinct chronological series of monuments is only possible when our observations are confined to a limited district, such as Switzerland.

The relative antiquity of the pile-dwellings, which belong respectively to the ages of stone and bronze, is clearly illustrated by the association of the tools with certain groups of animal remains. Where the tools are of stone, the castaway bones which served for the food of the ancient people are those of deer, the wild boar, and wild ox, which abounded when society was in the hunter state. But the bones of the later or bronze epoch were chiefly those of the domestic ox, goat, and pig, indicating progress in civilisation. Some villages of the stone age are of later date than others, and exhibit signs of an improved state of the arts. Among their relics are discovered carbonised grains of wheat and barley, and pieces of bread, proving that the cultivation of cereals had begun. In the same settlements, also, cloth, made of woven flax and straw, has been detected.

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[1] Bulletin de la Société Vaudoise des Sci. Nat., t. vi., Lausanne, 1860; and Antiquity of Man, by the author, ch. ii.

The pottery of the bronze age in Switzerland is of a finer texture, and more elegant in form, than that of the age of stone. At Nidau on the lake of Bienne, articles of iron have also been discovered, so that this settlement was evidently not abandoned till that metal had come into use.

At La Thène, in the northern angle of the lake of Neufchâtel, a great many articles of iron have been obtained, which in form and ornamentation are entirely different both from those of the bronze period and from those used by the Romans. Gaulish and Celtic coins have also been found there by MM. Schwab and Desor. They agree in character with remains, including many iron swords, which have been found at Tiefenau, near Berne, in ground supposed to have been a battle-field; and their date appears to have been anterior to the great Roman invasion of Northern Europe, though perhaps not long before that event.[1] Coins, which sometimes occur in deposits of the age of iron, have never yet been found in formations of the ages of bronze or stone.

The period of bronze must have been one of foreign commerce, as tin, which enters into this metallic mixture in the proportion of about ten per cent. to the copper, was obtained by the ancients chiefly from Cornwall.[2] Very few human bones of the bronze period have been met with in the Danish peat, or in the Swiss lake-dwellings, and this scarcity is generally attributed by archaeologists to the custom of burning the dead, which prevailed in the age of bronze.

PLEISTOCENE PERIOD.

From the foregoing observations we may infer that the ages of iron and bronze in Northern and Central Europe were preceded by a stone age, the Neolithic, referable to that division of the post-tertiary epoch which I have called Recent when the mammalia as well as the other organic remains accompanying the stone implements were of living species. But memorials have of late been brought to light of a still older age of stone, for which, as above stated, the name Paleolithic has been proposed, when man was contemporary in Europe with the elephant and rhinoceros, and various other animals, of which many of the most conspicuous have long since died out.

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[1] Sir J. Lubbock's Lecture, Royal Institution, Feb. 27th, 1863.

[2] Diodorus, v. 21, 22, and Sir H. James, Note on Block of Tin dredged up in Falmouth Harbour. Royal Institution of Cornwall, 1863.

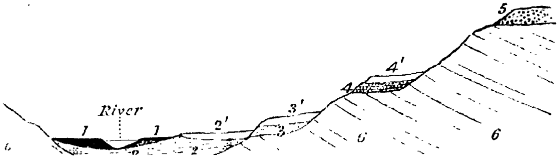
Reindeer Period in South of France.—In the larger number of the caves of Europe, as for example in those of England, Belgium, Germany, and many parts of France, the animal remains agree specifically with the fauna of the oldest division of the age of stone, or that to which belongs the drift of Amiens and Abbeville presently to be mentioned, containing flint implements of a very antique type. But there are some caves in the departments of Dordogne, Aude, and other parts of the south of France, which the late M. Lartet believed to be of intermediate date between the Paleolithic and Neolithic periods. To this intermediate era M. Lartet gave, in 1863, the name of the 'reindeer period,' because vast quantities of the bones and horns of that deer have been met with in the French caverns. In some cases separate plates of molars of the mammoth, and several teeth of the great Irish deer, *Cervus Megaceros*, and of the cave-lion, *Felis spelæa*, an extinct variety of *Felis leo*, have been found mixed up with cut and carved antlers of reindeer. On one of these sculptured bones in the cave of Perigord, a rude representation of the mammoth with its long curved tusks and covering of wool occurs, which is regarded by M. Lartet as placing beyond all doubt the fact that the early inhabitants of these caves must have seen this species of elephant still living in France. The presence of the marmot, as well as the reindeer and some other northern animals, in these caverns seems to imply a colder climate than that of the Swiss lake-dwellings, in which no remains of reindeer have as yet been discovered. The absence of this last in the old lacustrine habitations of Switzerland is the more significant, because in a cave in the neighbourhood of the lake of Geneva, namely that of Mont Salève, bones of the reindeer occur with flint implements similar to those of the caverns of Dordogne and Perigord.

The state of the arts, as exemplified by the instruments found in these caverns of the reindeer period, is somewhat more advanced than that which characterises the tools of the Amiens drift, but is nevertheless more rude than that of the Swiss lake-dwellings. No metallic articles occur, and the stone hatchets are not ground after the fashion of celts; the needles of bone are shaped in a workmanlike style, having their eyes drilled with consummate skill.

The formations above alluded to, which are as yet but imperfectly known, may be classed as belonging to the close of the Paleolithic era, of the monuments of which I am now about to treat.

Alluvial deposits of the Paleolithic age.—The alluvial and marine deposits of the Paleolithic age, the earliest to which any vestiges of man have yet been traced back, belong to a time when the physical geography of Europe differed in a marked degree from that now prevailing. In the Neolithic period, the valleys and rivers coincided almost entirely with those by which the present drainage of the land is effected, and the peat-mosses were the same as those now growing. The situation of the shell-mounds and lake-dwellings above alluded to is such as to imply that the topography of the districts where they are observed has not subsequently undergone any material alteration. Whereas we no sooner examine the Pleistocene (Post-pliocene) formations, in which the remains of so many extinct mammalia are found, than we at once perceive a more decided discrepancy between the former and present outline of the surface. Since those deposits originated, changes of considerable magnitude have been effected in the depth and width of many valleys, as also in the direction of the superficial and subterranean drainage, and, as is manifest near the sea-coast, in the relative position of land and water. In the annexed diagram (fig. 87) an ideal section is given, illustrating the different position which the Recent and Pleistocene alluvial deposits occupy in many European valleys.

Fig. 87.



Recent and Pleistocene alluvial deposits.

1. Peat of the recent period.
2. Gravel of modern river.
2'. Loam or brick-earth (loess) of same age as 2, formed by inundations of the river.
3. Lower-level valley-gravel with extinct mammalia (Pleistocene).
3'. Loam of same age
4. Higher-level valley-gravel (Pleistocene).
4'. Loam of same age.
5. Upland gravel of various kinds and periods, consisting in some places of unstratified boulder clay or glacial drift.
6. Older rocks.

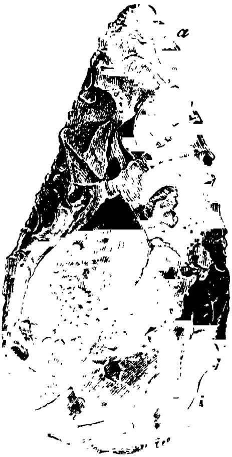
The peat No. 1 has been formed in a low part of the modern alluvial plain, in parts of which gravel No. 2 of the recent period is seen. Over this gravel the loam or fine sediment 2′ has in many places been deposited by the river during floods which covered nearly the whole alluvial plain.

No. 3 represents an older alluvium, composed of sand and gravel, formed before the valley had been excavated to its present depth. It contains the remains of fluviatile shells of living species associated with the bones of mammalia, in part of recent, and in part of extinct species. Among the latter the mammoth (*E. primigenius*) and the Siberian rhinoceros (*R. tichorhinus*) are the most common in Europe. No. 3′ is a remnant of the loam or brick earth by which No. 3 was overspread. No. 4 is a still older and more elevated terrace, similar in its composition and organic remains to No. 3, and covered in like manner with its inundation mud, 4′ Sometimes the valley gravels of older date are entirely missing, or there is only one, and occasionally there are more than two, marking as many successive stages in the excavation of the valley. They usually occur at heights varying from 10 to 100 feet, sometimes on the right, and sometimes on the left side of the existing river-plain, but rarely in great strength on exactly opposite sides of the valley.

Among the genera of extinct quadrupeds most frequently met with in England, France, Germany, and other parts of Europe, are the elephant, rhinoceros, hippopotamus, horse, great Irish deer, bear, tiger, and hyæna. In the peat No. 1 (fig. 87), and in the more modern gravel and silt (No. 2), works of art of the ages of iron and bronze, and of the later or Neolithic stone period, already described, are met with. In the more ancient or Paleolithic gravels, 3 and 4, there have been found of late years in several valleys in France and England—as, for example, in those of the Seine and Somme, and of the Thames and Ouse, near Bedford—stone implements of a rude type, showing that man coexisted in those districts with the mammoth and other extinct quadrupeds of the genera above enumerated. In 1847, M. Boucher de Perthes observed in an ancient alluvium at Abbeville, in Picardy, the bones of extinct mammalia associated in such a manner with flint implements of a rude type as to lead him to infer that both the organic remains and the works of art were referable to one and the same period. This inference was soon after confirmed by Mr. Prestwich, who found in 1859 a flint tool in situ in the same stratum at Amiens that contained the remains of extinct mammalia.

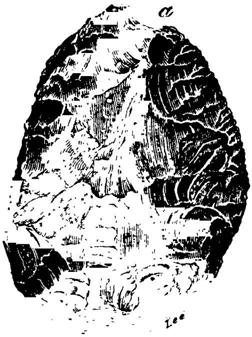
The flint implements found at Abbeville and Amiens are most of them considered to be hatchets and spear-heads (figs. 88 and 89), and are different from those commonly called 'celts' (fig. 90). These celts, so often found in the recent formations, have a more regular oblong shape, the result of grinding, by which also a sharp edge has been given to them. The Abbeville tools found in gravel at different levels, as in Nos. 3 and 4,

Fig. 88.



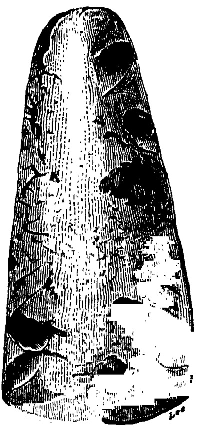
Unpolished spear-head-shaped flint implement. St. Acheul. One-third of the original size.

Fig. 89.



Unpolished oval-shaped flint hatchet. Mautort, near Abbeville. One-third of the original size.

Fig. 90.



Polished celt found at Coton, Cambridgeshire, 1863. One-half of the original size.

fig. 87, in which bones of the elephant, rhinoceros, and other extinct mammalia occur, are always unground, having evidently been brought into their present form simply by the chipping off of fragments of flint by repeated blows, such as could be given by a stone hammer.

Some of them are oval, others of a spear-headed form, no two exactly alike, and yet the greater number of each kind are obviously fashioned after the same general pattern. Their outer surface is often white, the original black flint having been discoloured and bleached by exposure to the air, or by the action of acids, as they lay in the gravel. They are most commonly stained of the same ochreous colour as the flints of the gravel in which they are imbedded. Occasionally their antiquity is indicated not only by their colour but by superficial incrustations of carbonate of lime, or by dendrites formed of oxide of iron and manganese. The edges also of most of them are worn, sometimes by having been used as tools, or sometimes by having been rolled in the old river's bed. They are met with not only in the lower-level gravels, as in No. 3, fig. 87, but also in No. 4, or the higher gravels, as at St. Acheul, in the suburbs of Amiens, where the old alluvium lies at an elevation of about 100 feet above the level of the river Somme. At both levels fluviatile and land-shells are met with in the loam as well as in the gravel, but there are no marine shells associated, except at Abbeville, in the lowest part of the gravel, near the sea, and a few feet only above the present high-water mark. Here with fossil shells of living species are mingled the bones of *Elephas primigenius* and *E. antiquus*, *Rhinoceros tichorhinus*, *Hippopotamus*, *Felis leo* (*var. spelæa*,) *Hyæna crocuta* (*var. spelæa*), reindeer, and many others, the bones accompanying the flint implements in such a manner as to show that both were buried in the old alluvium at the same period.

Nearly the entire skeleton of a rhinoceros was found at one point, namely, in the Menchecourt drift at Abbeville, the bones being in such juxtaposition as to show that the cartilage must have held them together at the time of their inhumation.

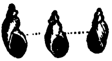
The general absence here and elsewhere of human bones from gravel and sand in which flint tools are discovered, may in some degree be due to the present limited extent of our researches. But it may also be presumed that when a hunter population, always scanty in numbers, ranged over this region, they were too wary to allow themselves to be overtaken by the floods which swept away many herbivorous animals from the low river-plains where they may have been pasturing or sleeping. Beasts of prey prowling about the same alluvial flats in search of food may also have been surprised more readily than the human tenant of the same region, to whom the signs of a coming tempest were better known.

Inundation-mud of rivers.—Brick-earth.—Fluviatile loam, or loess.—As a general rule, the fluviatile alluvia of different ages (Nos. 2, 3, 4, fig. 87) are severally made up of coarse materials in their lower portions, and of fine silt or loam in their upper parts. For rivers are constantly shifting their position in the valley-plain, encroaching gradually on one bank, near which there is deep water, and deserting the other or opposite side, where the channel is growing shallower, being destined eventually to be converted into land. Where the current runs strongest, coarse gravel is swept along, and where its velocity is slackened, first sand, and then only the finest mud, is thrown down. A thin film of this fine sediment is spread, during floods, over a wide area, on one, or sometimes on both sides, of the main stream, often reaching as far as the base of the bluffs or higher grounds which bound the valley. Of such a description are the well-known annual deposits of the Nile, to which Egypt owes its fertility. So thin are they, that the aggregate amount accumulated in a century is said rarely to exceed five inches, although in the course of thousands of years it has attained a vast thickness, the bottom not having been reached by borings extending to a depth of 60 feet towards the central parts of the valley. Everywhere it consists of the same homogeneous mud, destitute of stratification—the only signs of successive accumulation being where the Nile has silted up its channel, or where the blown sands of the Libyan desert have invaded the plain, and given rise to alternate layers of sand and mud.

In European river-loams we occasionally observe isolated pebbles and angular pieces of stone which have been floated by ice to the places where they now occur ; but no such coarse materials are met with in the plains of Egypt.

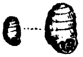
In some parts of the valley of the Rhine the accumulation of similar loam, called in Germany 'loess,' has taken place on an enormous scale. Its colour is yellowish-grey, and very homogeneous ; and Professor Bischoff has ascertained, by analysis, that it agrees in composition with the mud of the Nile. Although for the most part unstratified, it betrays in some places marks of stratification, especially where it contains calcareous concretions, or in its lower part where it rests on subjacent gravel and sand which alternate with each other near the junction. About a sixth part of the whole mass is composed of carbonate of lime, and there is usually an intermixture of fine quartzose and micaceous sand.

Fig. 91.



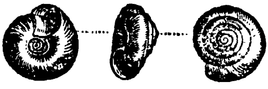
Succinea elongata.

Fig. 92.



Pupa muscorum (Linn.).

Fig. 93.



Helix hispida (plebeia) (Linn.).

Although this loam of the Rhine is unsolidified, it usually terminates where it has been undermined by running water in a vertical cliff, from the face of which shells of terrestrial, freshwater and amphibious mollusks project in relief. These shells do not imply the permanent sojourn of a body of fresh water on the spot, for the most aquatic of them, the *Succinea*, inhabits marshes and wet grassy meadows. The *Succinea elon-*

gata (or *S. oblongata*), fig. 91, is very characteristic both of the loess of the Rhine and of some other European river-loams.

Among the land-shells of the Rhenish loess, *Helix hispida*, fig. 93, and *Pupa muscorum*, fig. 92, are very common. Both the terrestrial and aquatic shells are of most fragile and delicate structure, and yet they are almost invariably perfect and uninjured. They must have been broken to pieces had they been swept along by a violent inundation. Even the colour of some of the land-shells, as that of *Helix nemoralis*, is occasionally preserved.

In parts of the valley of the Rhine, between Bingen and Basle, the fluviatile loam or loess now under consideration is several hundred feet thick, and contains here and there throughout that thickness land and amphibious shells. As it is seen in masses fringing both sides of the great plain, and as occasionally remnants of it occur in the centre of the valley, forming hills several hundred feet in height, it seems necessary to suppose, first, a time when it slowly accumulated ; and secondly, a later period, when large portions of it were removed, or when the original valley, which had been partially filled up with it, was re-excavated.

Such changes may have been brought about by a great movement of oscillation, consisting first of a general depression of the land, and then of a gradual re-elevation of the same. The amount of continental depression which first took place in the interior, must be imagined to have exceeded that of the region near the sea, in which case the higher part of the great valley would have its alluvial plain gradually raised by an accumulation of sediment, which would only cease when the subsidence of the land was at an end. If the direction of the movement was then reversed, and, during the re-elevation of the continent, the inland region nearest the mountains should rise more rapidly than that near the coast, the river would acquire a denuding power sufficient to enable it to sweep away gradually nearly all the loam and gravel with which parts of its basin had been filled up. Terraces and hillocks of mud and sand would then alone remain to attest the various levels at which the river had thrown down and afterwards removed alluvial matter.

Cavern deposits containing human remains and bones of extinct animals.—In England, and in almost all countries where limestone rocks abound, caverns are found, usually consisting of cavities of large dimensions, connected together by low, narrow, and sometimes tortuous galleries or tunnels. These subterranean vaults are usually filled in part with mud, pebbles, and breccia, in which bones occur belonging to the same assemblage of animals as those characterising the Pleistocene (Post-pliocene) alluvia above described. Some of these bones are referable to extinct and others to living species, and they are occasionally intermingled, as in the valley gravels, with implements of one or other of the great divisions of the stone age, and these are not unfrequently accompanied by human bones, which are much more common in cavern deposits than in valley alluvium.

Each suite of caverns, and the passages by which they communicate the one with the other, afford memorials to the geologist of successive phases through which they must have passed. First, there was a period when the carbonate of lime was carried out gradually by springs; secondly, an era when engulfed rivers or occasional floods swept organic and inorganic *débris* into the subterranean hollows previously formed; and thirdly, there were such changes in the configuration of the region as caused the engulfed rivers to be turned into new channels, and springs to be dried up, after which the cave-mud, breccia, gravel, and fossil bones would bear the same kind of relation to the existing drainage of the country as the older valley-drifts with their extinct mammalian remains and works of art bear to the present rivers and alluvial plains.

The quarrying away of large masses of Carboniferous and Devonian limestone, near Liége, in Belgium, has afforded the geologist magnificent sections of some of these caverns, and the former communication of cavities in the interior of the rocks with the old surface of the country by means of vertical or oblique fissures, has been demonstrated in places where it would not otherwise have been suspected, so completely have the upper extremities of these fissures been concealed by superficial drift, while their lower ends, which extended into the roofs of the caves, are masked by stalactitic incrustations.

The origin of the stalactite has been thus explained by the eminent chemist Liebig. Mould or humus, being acted on by moisture and air, evolves carbonic acid, which is dissolved by rain. The rain water, thus impregnated, permeates the porous limestone, dissolves a portion of it, and afterwards, when the excess of carbonic acid evaporates in the caverns, parts with the calcareous matter, and forms stalactite. Even while caverns are still liable to be occasionally flooded such calcareous incrustations accumulate, but it is generally when they are no longer in the line of drainage that a solid floor of hard stalagmite is formed on the bottom.

The late Dr. Schmerling examined forty caves near Liége, and found in all of them the remains of the same fauna, comprising the mammoth, tichorhine rhinoceros, cave-bear, cave-hyæna, cave-lion, and many others, some of extinct and some of living species, and in all of them flint implements. In four or five caves only parts of human skeletons were met with, comprising sometimes skulls with a few other bones, sometimes nearly every part of the skeleton except the skull. In one of the caves, that of Engihoul, where Schmerling had found the remains of at least three human individuals, they were mingled in such a manner with bones of extinct mammalia, as to leave no doubt on his mind (in 1833) of man having coexisted with them.

In 1860, Professor Malaise, of Liége, explored with me this same cave of Engihoul, and beneath a hard floor of stalagmite we found mud full of the bones of extinct and recent animals, such as Schmerling had described, and my companion persevering in his researches after I had returned to England, extracted from the same deposit two human lower jaw-bones retaining their teeth. The skulls from these Belgian caverns display no marked deviation from the normal European type of the present day.

The careful investigations carried on by Dr. Falconer, Mr. Pengelly, and others, in the Brixham cave near Torquay, in 1858, demonstrated that flint knives were there embedded in such a manner in loam underlying a floor of stalagmite as to prove that man had been an inhabitant of that region when the cave-bear and other members of the ancient Pleistocene fauna were also in existence.

The absence of gnawed bones had led Dr. Schmerling to infer that none of the Belgian caves which he explored had served as the dens of wild beasts ; but there are many caves in Germany and England which have certainly been so inhabited, especially by the extinct hyæna and bear.

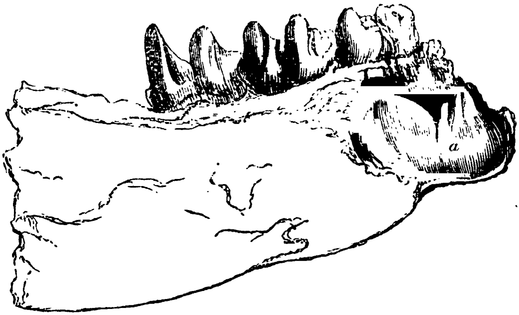
A fine example of a hyæna's den was afforded by the cave of Kirkdale, so well described by the late Dr. Buckland in his *Reliquiæ Diluvianæ*. In that cave, above twenty-five miles NNE. of York, the remains of about 300 hyænas, belonging to individuals of every age, were detected. The species (*Hyæna spelæa*) has been considered by paleontologists as extinct ; it was larger than the fierce *Hyæna crocuta* of South Africa, which it closely resembled, and of which it is regarded by Mr. Boyd Dawkins as a variety. Dr. Buckland, after carefully examining the spot, proved that the hyænas must have lived there ; a fact attested by the quantity of their dung, which, as in the case of the living hyæna, is of nearly the same composition as bone, and almost as durable. In the cave were found the remains of the ox, young elephant, hippopotamus, rhinoceros, horse, bear, wolf, hare, water-rat, and several birds. All the bones have the appearance of having been broken and gnawed by the teeth of the hyænas; and they occur confusedly mixed in loam or mud, or dispersed through a crust of stalagmite which covers it. In these and many other cases it is supposed that portions of herbivorous quadrupeds have been dragged into caverns by beasts of prey, and have served as their food—an opinion quite consistent with the known habits of the living hyæna.

Australian cave-breccias.—Ossiferous breccias are not confined to Europe, but occur in all parts of the globe; and those discovered in fissures and caverns in Australia correspond closely in character with what has been called the bony breccia of the Mediterranean, in which the fragments of bone and rock are firmly bound together by a red ochreous cement.

Some of these caves were examined by the late Sir T. Mitchell in the Wellington Valley, New South Wales, about 210 miles west of Sydney, on the river Bell, one of the principal sources of the Macquarie, and on the Macquarie itself. The caverns often branch off in different directions through the rock, widening and contracting their dimensions, and the roofs and floors are covered with stalactite. The bones are often broken, but do not seem to be water-worn. In some places they lie embedded in loose earth, but they are usually included in a breccia.

The remains belong to marsupial animals. Among the most abundant are those of the kangaroo, of which there are four species, while others belong to the genera *Phascolomys*, the wombat; *Dasyurus*, the ursine opossum; *Phalangista*, the vulpine opossum; and *Hypsiprymnus*, the kangaroo-rat.

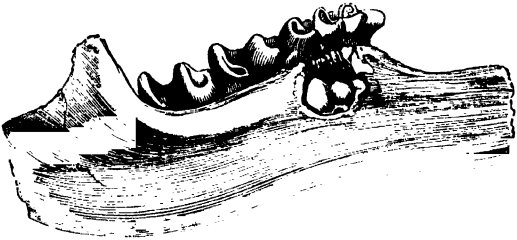
Fig. 94.



Part of lower jaw of *Macropus atlas*. Owen. A young individual of an extinct species. *a*. Permanent false molar, in the alveolus.

In the fossils above enumerated, several species are larger than the largest living ones of the same genera now known in Australia. The preceding figure of the right side of a lower jaw of a fossil kangaroo (*Macropus atlas*, Owen) will at once be seen to exceed in magnitude the corresponding part of the largest living kangaroo, which is represented in fig. 95. In both these specimens part of the substance of the jaw has been broken open, so as to show the permanent false molar (*a*, fig. 94), concealed in the socket. From the fact of this molar not having been cut, we learn that the individual was young, and had not shed its first teeth.

Fig. 95.



Lower jaw of largest living species of kangaroo.
(*Macropus major.*)

The reader will observe that all these extinct quadrupeds of Australia belong to the marsupial family, or, in other words, that they are referable to the same peculiar type of organisation which now distinguishes the Australian mammalia from those of other parts of the globe. This fact is one of many pointing to a general law deducible from the fossil vertebrate and invertebrate animals of times immediately antecedent to our own, namely, that the present geographical distribution of organic *forms* dates back to a period anterior to the origin of existing *species*; in other words, the limitation of particular genera or families of quadrupeds, mollusca, &c., to certain existing provinces of land and sea, began before the larger part of the species now contemporary with man had been introduced into the earth.

Professor Owen, in his excellent 'History of British Fossil Mammals,' has called attention to this law, remarking that the fossil quadrupeds of Europe and Asia differ from those of Australia or South America. We do not find, for example, in the Europæo-Asiatic province fossil kangaroos, or armadillos, but the elephant, rhinoceros, horse, bear, hyæna, beaver, hare, mole, and others, which still characterise the same continent.

In like manner, in the Pampas of South America the skeletons of Megatherium, Megalonyx, Glyptodon, Mylodon, Toxodon, Macrauchenia, and other extinct forms, are analogous to the living sloth, armadillo, cavy, capybara, and llama. The fossil quadrumana, also associated with some of these forms in the Brazilian caves, belong to the Platyrrhine family of monkeys, now peculiar to South America. That the extinct fauna of Buenos Ayres and Brazil was very modern has been shown by its relation to deposits of marine shells, agreeing with those now inhabiting the Atlantic.

The law *of geographical relationship above alluded to, between the living vertebrata of every great zoological province* and the fossils of the period immediately antecedent, even where the fossil species are extinct, is by no means confined to the mammalia. New Zealand, when first examined by Europeans, was found to contain no indigenous land quadrupeds, no kangaroos, or opossums, like Australia; but a small bird wingless or with very rudimentary wings abounded there, the smallest living representative of the ostrich family, called the Kiwi by the natives (*Apteryx*). In the fossils of the Pleistocene period in this same island, there is the like absence of kangaroos, opossums, wombats, and the rest; but in their place a prodigious number of well-preserved specimens of gigantic birds of the struthious order, belonging to genera called by Owen *Dinornis* and *Palapteryx*, which are entombed in superficial deposits. These genera comprehended many species, some of which were four, some seven, others nine, and others eleven feet in height! It seems doubtful whether any contemporary mammalia shared the land with this population of gigantic feathered bipeds.

Mr. Darwin, when describing the recent and fossil mammalia of South America, has dwelt much on the wonderful relationship of the extinct to the living types in that part of the world, inferring from such geographical phenomena that the existing species are all related to the extinct ones which preceded them by a bond of common descent.

Climate of the Pleistocene period.—The evidence as to the climate of Europe during this epoch is somewhat conflicting. The fluviatile and land-shells are all of existing species, but their geographical range has not always been the same as at present. Some, for example, which then lived in Britain are now only found in Norway and Finland, probably implying that the Pleistocene climate of Britain was colder, especially in the winter. So also the reindeer and the musk sheep (*Ovibos moschatus*), now inhabitants of the Arctic regions, occur fossil in the valleys of the Thames and Avon, and also in France and

Germany, accompanied in most places by the mammoth and the woolly rhinoceros. At Grays in Essex, on the other hand, another species both of elephant and of rhinoceros occur, together with a hippopotamus and the *Cyrena fluminalis*, a shell now extinct in Europe but still an inhabitant of the Nile and some Asiatic rivers. With it occurs the *Unio littoralis* now living in the Seine and Loire. In the valley of the Somme flint tools have been found associated with *Hippopotamus major* and *Cyrena fluminalis* in the lower level Pleistocene gravels; while in the higher level (and more ancient) gravels similar tools are more abundant, and are associated with the bones of the mammoth and other Pleistocene quadrupeds, indicative of a colder climate.

It is possible that we may here have evidence of summer and winter migrations rather than of a general change of temperature. Instead of imagining that the hippopotamus lived all the year round with the musk-ox and lemming, we may rather suppose that the apparently conflicting evidence may be due to the place of our observations being near the boundary line of a northern and southern fauna, either of which may have advanced or receded during comparatively slight and temporary fluctuations of climate. There may then have been a continuous land communication between England and the North of Siberia, as well as in an opposite direction with Africa, then united to Southern Europe.

In drift at Fisherton, near Salisbury, thirty feet above the river Wiley, the Greenland lemming and a new species of the Arctic genus *Spermophilus* have been found, along with the mammoth, reindeer, cave-hyæna, and other mammalia suited to a cold climate. A flint implement was taken out from beneath the bones of the mammoth. In a higher and older deposit in the vicinity, flint tools like those of Amiens have been discovered. Nearly all the known Pleistocene (Post-pliocene) quadrupeds have now been found accompanying flint knives or hatchets in such a way as to imply their coexistence with man; and we have thus the concurrent testimony of several classes of geological facts to the vast antiquity of the human race. In the first place, the disappearance of a great variety of species of wild animals from every part of a wide continent must have required a vast period for its accomplishment; yet this took place while man existed upon the earth, and was completed before that early period when the Danish shell mounds were formed or the oldest of the Swiss lake-dwellings constructed. Secondly, the deepening and widening of valleys, indicated by the position of the river gravels at various heights, implies an amount of change of which that which has occurred during the historical period forms a scarcely perceptible part. Thirdly, the change in the course of rivers which once flowed through caves now removed from any line of drainage, and the formation of solid floors of stalagmite, must have required a great lapse of time. Lastly, ages must have been required to change the climate of wide regions to such an extent as completely to alter the geographical distribution of many mammalia as well as land and fresh-water shells. The 3,000 or 4,000 years of the historical period do not furnish us with any appreciable measure for calculating the number of centuries which would suffice for such a series of changes, which are by no means of a local character, but have operated over a considerable part of Europe.

Relative longevity of species in the mammalia and testacea.—I called attention in 1830[1] to the fact, which had not at that time attracted notice, that the association in the Pleistocene deposits of shells, exclusively of living species, with many extinct quadrupeds, betokened a longevity of species in the testacea far exceeding that in the mammalia. Subsequent researches seem to show that this greater duration of the same specific forms in the class mollusca is dependent on a still more general law, namely, that the lower the grade of animals, or the greater the simplicity of their structure, the more persistent are they in general in their specific characters throughout vast periods of time. Not only have the invertebrata, as shown by geological data, altered at a less rapid rate than the vertebrata, but if we take one of the classes of the former, as for example the mollusca, we find those of more simple structure to have varied at a slower rate than those of a higher and more complex organisation; the brachiopoda, for example, more slowly than the lamellibranchiate bivalves, while the latter have been more persistent than the univalves, whether gasteropoda or cephalopoda. In like manner the specific identity of the characters of the foraminifera, which are among the lowest types of the invertebrata, has outlasted that of the mollusca in an equally decided manner.

Teeth of Pleistocene mammalia.—To those who have never studied comparative anatomy, it may seem scarcely credible that a single bone taken from any part of the skeleton may enable a skilful osteologist to distinguish, in many cases, the genus, and sometimes the species of quadrupeds to which it belonged. Although few geologists can aspire to such knowledge, which must be the result of long practice and study, they will nevertheless derive great advantage from learning,

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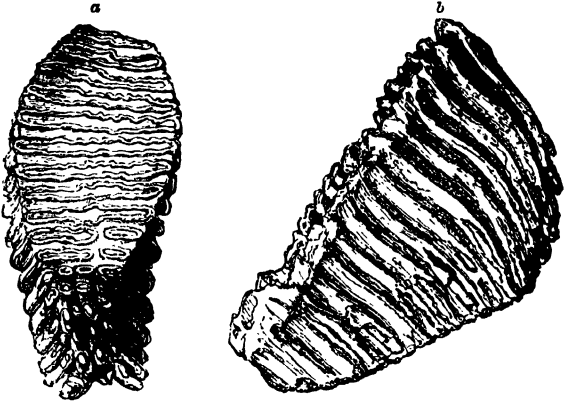
[1] Principles of Geology, 1st ed. vol. iii. p. 140.

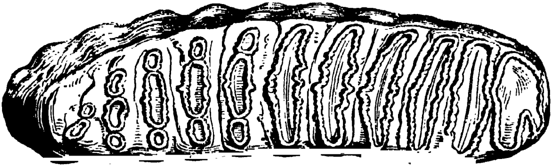
Fig. 96.



Elephas primigenius (or Mammoth); molar of upper jaw, right side; one-third of natural size. Pleistocene.

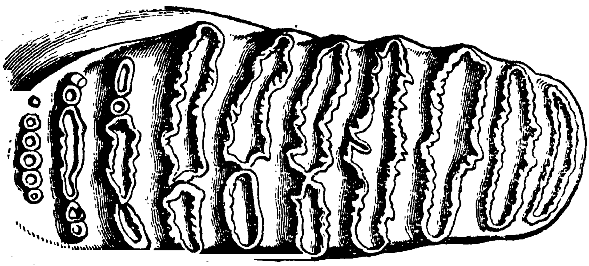
a. grinding surface. *b.* side view.

Fig. 97.



Elephas antiquus, Falconer. Penultimate molar, one-third of natural size. Pleistocene and Pliocene.

Fig. 98.



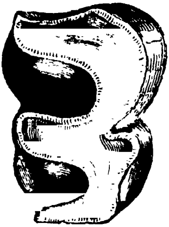
Elephas meridionalis, Nesti. Penultimate molar, one-third of natural size. Newer Pliocene.

what is comparatively an easy task, to distinguish the principal divisions of the mammalia by the forms and characters of their teeth.

The annexed figures represent the teeth of some of the more common species and genera found in alluvial and cavern deposits.

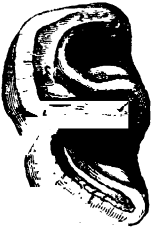
On comparing the grinding surfaces of the corresponding molars of the three species of elephants, figs. 96, 97, 98, it will be seen that the folds of enamel are most numerous in the mammoth; fewer and wider, or more open, in *E. antiquus*; and

Fig. 99.



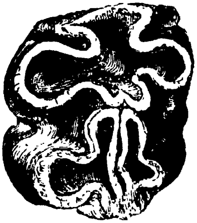
Rhinoceros leptorhinus, Cuvier—*Rhin. megarhinus*, Christol; fossil from freshwater beds of Grays, Essex (see p. 138); penultimate molar, lower jaw, left side; two-thirds of nat. size. Pleistocene and Newer pliocene.

Fig. 100.



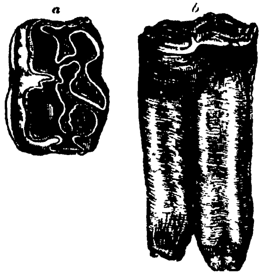
Rhinoceros tichorhinus; penultimate molar, lower jaw, left side; two-thirds of nat. size. Pleistocene.

Fig. 101.



Hippopotamus; from cave near Palermo; molar tooth; two-thirds of nat. size. Pleistocene.

Fig. 102.

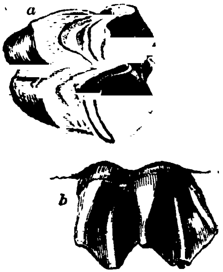


Horse.

Equus caballus, L. (common horse); from the shell-marl, Forfarshire; second molar, lower jaw. Recent.

a. grinding surface, two-thirds nat. size.
b. side view of same, half nat. size.

Fig. 103.



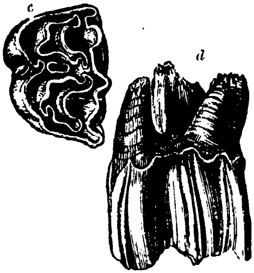
Deer.

Elk (*Cervus alces*, L.); recent; molar of upper jaw.

a. grinding surface.
b. side view; two-thirds of nat. size.

most open and fewest in *E. meridionalis*. It will be also seen that the enamel in the molar of the *Rhinoceros tichorhinus* (fig. 100), is much thicker than in that of the *Rhinoceros leptorhinus* (fig. 99).

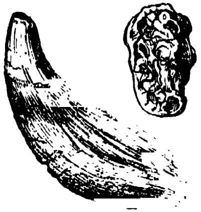
Fig. 104.



Ox.

Ox, common, from shell marl, Forfarshire; true molar, upper jaw; two-thirds nat. size. Recent.
c. Grinding surface.
d. side view; fangs uppermost.

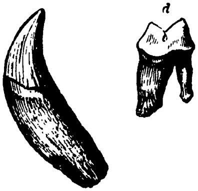
Fig. 105.



Bear.

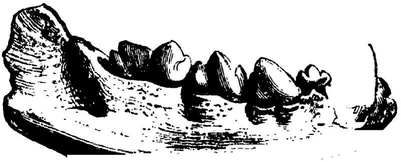
a. canine tooth or tusk of bear (*Ursus spelæus*); from cave near Liége.
b. molar of left side, upper jaw; one-third of nat. size. Pleistocene.

Fig. 106.



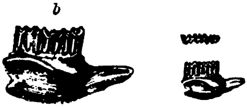
Tiger.
c. canine tooth of tiger (*Felis tigris*); recent.
d. outside view of posterior molar, lower jaw; one-third of nat. size; recent.

Fig. 107.



Hyæna spelæa, Goldf. (variety of *H. crocuta*); lower jaw. Kent's Hole, Torquay, Devonshire. One-third nat. size. Pleistocene.

Fig. 108.



Teeth of a new species of *Arvicola*, field-mouse; from the Norwich Crag. Newer pliocene.
a. grinding surface. *b.* side view of same. *c.* nat. size of *a* and *b*.

CHAPTER XI.

PLEISTOCENE PERIOD CONTINUED.—GLACIAL CONDITIONS.[1]

Geographical distribution, form, and characters of glacial drift—Fundamental rocks, polished, grooved, and scratched—Abrading and striating action of glaciers—Moraines, erratic blocks, and 'Roches Moutonnées'—Alpine blocks on the Jura—Continental ice of Greenland—Ancient centres of the dispersion of erratics—Transportation of drift by floating icebergs—Bed of the sea furrowed and polished by the running aground of floating ice-islands.

Character and distribution of glacial drift.—In speaking of the loose transported matter commonly found on the surface of the land in all parts of the globe, I alluded to the exceptional character of what has been called the boulder formation in the temperate and Arctic latitudes of the northern hemisphere. The peculiarity of its form in Europe north of the 50th, and in North America north of the 40th parallel of latitude, is now universally attributed to the action of ice, and the difference of opinion respecting it is now chiefly restricted to the question whether land-ice or floating icebergs have played the chief part in its distribution. It is wanting in the warmer and equatorial regions, and reappears when we examine the lands which lie south of the 40th and 50th parallels in the southern hemisphere, as, for example, in Patagonia, Terra del Fuego, and New Zealand. It consists of sand and clay, sometimes stratified, but often wholly devoid of stratification for a depth of 50, 100, or even a greater number of feet. To this unstratified form of the deposit the name of *till* has long been applied in Scotland. It generally contains a mixture of angular and rounded fragments of rock, some of large size, having occasionally one or more of their sides flattened and smoothed, or even highly polished. The smoothed surfaces usually exhibit many scratches parallel to each other, one set of which often crosses an older set. The till is almost everywhere wholly devoid of organic remains, except those washed into it from older formations, though in some places it contains marine shells usually of northern or Arctic species, and frequently in a fragmentary state. The bulk of the till has usually been derived from the grinding down into mud of rocks in the immediate neighbourhood, so that it is red in a region of Red Sandstone, as in Strathmore in Forfarshire ; grey or black in a district of coal and bituminous shale, as around Edinburgh ; and white in a chalk country, as in parts of Norfolk and Denmark. The stony fragments dispersed irregularly through the till usually belong, especially in mountainous countries, to rocks found in some part of the same hydrographical basin ; but there are regions where the whole of the boulder clay has come from a distance, and huge blocks, or 'erratics,' as they have been called, many feet in diameter, have not unfrequently travelled hundreds of miles from their point of departure, or from the parent rocks from which they have evidently been detached. These are commonly angular, and have often one or more of their sides polished and furrowed.

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[1] As to the former excess of cold, whether brought about by modifications in the height and distribution of the land or by altered astronomical conditions, see Principles, vol. i. (11th ed., 1872), chaps. xii. and xiii. 'Vicissitudes of Climate.'

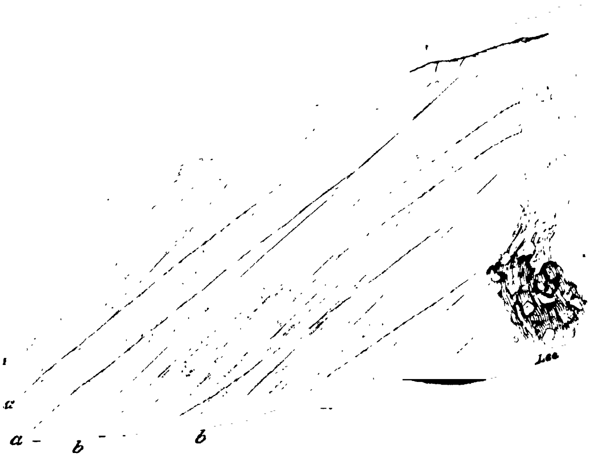
The rock on which the boulder formation reposes, if it consists of granite, gneiss, marble, or other hard stone, capable of permanently retaining any superficial markings which may have been imprinted upon it, is usually smoothed or polished, like the erratics above described ; and exhibits parallel striæ and furrows having a determinate direction. This direction, both in Europe and North America, agrees generally in a marked manner with the course taken by the erratic blocks in the same district. The boulder clay, when it was first studied, seemed in many of its characters so singular and anomalous, that geologists despaired of ever being able to interpret the phenomena by reference to causes now in action. In those exceptional cases, where marine shells of the same date as the boulder clay were found, nearly all of them were recognised as living species—a fact conspiring with the superficial position of the drift to indicate a comparatively modern origin.

The term 'diluvium' was for a time the most popular name of the boulder formation, because it was referred by many to the deluge of Noah, while others retained the name as expressive of their opinion that a series of diluvial waves raised by hurricanes and storms, or by earthquakes, or by the sudden upheaval of land from the bed of the sea, had swept over the continents, carrying with them vast masses of mud and heavy stones, and forcing these stones over rocky surfaces so as to polish and imprint upon them long furrows and striæ. But geologists were not long in seeing that the boulder formation was characteristic of high latitudes, and that on the whole the size and number of erratic blocks increases as we travel towards the Arctic regions.

They could not fail to be struck with the contrast which the countries bordering the Baltic presented when compared with those surrounding the Mediterranean. The multitude of travelled blocks and striated rocks in the one region, and the absence of such appearances in the other, were too obvious to be overlooked. Even the great development of the boulder formation, with large erratics so far south as the Alps offered an exception to the general rule, favourable to the hypothesis that there was some intimate connection between it and accumulations of snow and ice.

Transporting and abrading power of glaciers.—I have described elsewhere ('Principles,' vol. i. chap. xvi. 1867) the manner in which the snow of the Alpine heights is prevented from accumulating indefinitely in thickness by the constant descent of a large portion of it by gravitation. Becoming converted into ice it forms what are termed glaciers, which glide down the principal valleys. On their surface are seen long lines or linear heaps of sand and mud, with angular fragments of rock which fall from the steep slopes or precipices bounding the glaciers. These lines being arranged along the sides of the

Fig. 109.



Limestone, polished, furrowed, and scratched by the glacier of Rosenlaui in Switzerland. (Agassiz.)

a a. White streaks or scratches, caused by small grains of flint frozen into the ice.
b b. Furrows.

glacier are termed *lateral moraines.* When two glaciers meet and continue their course as one glacier, the right lateral moraine of the one, and the left of the other meet together in the centre of the joint glacier forming what is called a *medial moraine.* When in Switzerland a glacier, laden with mud and stones, descends so far as to reach a region about 3,500 feet above the level of the sea, the warmth of the air is such that it melts rapidly in summer, and all the mud, sand, and pieces of rock, are slowly deposited at its lower end, forming a confused heap of unstratified rubbish called a *terminal moraine* and much resembling the *till* before described (p. 144).

Besides the blocks thus carried down on the top of the glacier, many fall through fissures in the ice to the bottom, where some of them become firmly frozen into the mass, and are pushed along the base of the glacier, abrading, polishing, and grooving the rocky floor below, as a diamond cuts glass, or as emery powder polishes steel, and the larger blocks are reciprocally grooved and polished by the rocky floor on their lower sides. The striæ which are made, and the deep grooves which are scooped out by this action, are rectilinear and parallel to an extent never seen in those produced on loose stones or rocks, where shingle is hurried along by a torrent, or by the waves on a sea-beach. In addition to these polished, striated, and grooved surfaces of rock, another proof of the former action of a glacier is afforded by the 'roches moutonnées,' or projecting eminences of rock which have been smoothed and worn into the shape of flattened domes by the glacier as it passed over them. They have been traced in the Alps to great heights above the present glaciers, and to great horizontal distances beyond them. Another effect of a glacier is to lodge a ring of stones round the summit of a conical peak which may happen to project through the ice. If the glacier is lowered greatly by melting, these large angular fragments, which are called 'perched blocks,' are left in a singular situation near the top of a steep hill or pinnacle, the lower parts of which may be destitute of boulders.

Alpine blocks on the Jura.—The moraines, erratics, polished surfaces, domes, perched blocks and striæ, above described, are observed in the great valley of Switzerland, fifty miles broad; and on the Jura, a chain which lies to the north of this valley. The average height of the Jura is about one-third that of the Alps, and it is now entirely destitute of glaciers; yet it also presents moraines, and polished and grooved surfaces. The erratics, moreover, which cover it, present a phenomenon which has astonished and perplexed the geologist for more than half a century. No conclusion can be more incontestable than that these angular blocks of granite, gneiss, and other crystalline formations, came from the Alps, and that they have been brought for a distance of fifty miles and upwards across one of the widest and deepest valleys in the world; so that they are now lodged on a chain composed of limestone and other formations, altogether distinct from those of the Alps. Their great size and angularity, after a journey of so many leagues, has justly excited wonder; for hundreds of them are as large as cottages; and one in particular, composed of gneiss, celebrated under the name of Pierre à Bot, rests on the side of a hill about 900 feet above the lake of Neufchatel, and is no less than 40 feet in diameter.

In the year 1821, M. Venetz first announced his opinion that the Alpine glaciers must formerly have extended far beyond their present limits, and the proofs, appealed to by him in confirmation of this doctrine were acknowledged by all subsequent observers, and greatly strengthened by new observations and arguments. M. Charpentier supposed that when the glaciers extended continuously from the Alps to the Jura, the former mountains were 2,000 or 3,000 feet higher than at present, Other writers, on the contrary, conjectured that the whole country had been submerged, and the moraines and erratic blocks transported on floating icebergs; but a careful study of the distribution of the travelled masses, and the total absence of marine shells from the old glacial drift of Switzerland, have gone far to disprove this last hypothesis. M. Guyot had, in 1845, endeavoured to show that the Alpine erratics, instead of being scattered at random over the Jura and the great plain of Switzerland, as they would have been if they had been conveyed to their present sites by water, are arranged in a certain determinate order, strictly analogous to that which ought to prevail if they had once constituted the lateral, medial, and terminal moraines of great glaciers. The rocks chiefly relied on as evidence of this distribution consist of three varieties of granite, besides gneiss, chlorite-slate, euphotide, serpentine, and a peculiar kind of conglomerate; all of them mineral compounds, foreign alike to the great strath between the Alps and Jura, and to the structure of the Jura itself.

Some geologists have objected to the theory of the transportation by glaciers of Alpine erratics to the Jura, on the ground that according to the present relative altitude of the two chains, the glaciers coming from the Alps could not have had an angle of inclination sufficiently great to carry their moraines to such heights on the inferior chain. This objection, if valid, would seem to have been strengthened by the discovery of a block of granitic rock about thirteen feet in its longest diameter, resting on a height of the Jura called Buren Kopf, near Soleure. When I visited Soleure in the summer of 1873, my companion, Prof. Hughes, of Cambridge, ascertained the height of this block to be 4,037 Swiss feet (3,970 English feet) above the level of the sea.

But I do not consider that we have any right to assume that the relative heights of the Alps and Jura have remained unaltered since the era of the transportation of the erratics, still less that the change of level which last took place was uniform over a great district, whether in quantity or direction. On the contrary, our experience during the best authenticated earthquakes would lead to precisely opposite conclusions, assuming that the present operations of nature ought to be taken as our safest guide in regard to her course in past time. During the earthquake of January 1855,[1] in the north island of New Zealand, the point of maximum elevation as clearly shown on the sea-coast, and carefully measured by a competent scientific observer, was nine feet, and it was ascertained that it remained the same for many months after the shock. From the line of greatest upheaval the change of level gradually diminished when traced from NE. to SW., until at the end of twenty-three miles it died out, and gave place in the southern island south of Cook's Straits to a depression of five feet, so that after the earthquake, ships were obliged to go three miles higher up the river Wairau to obtain a supply of fresh water.

We may well suppose that the movements which went on in the Alps and Jura, instead of being uniform, may, according to the analogy of these movements in New Zealand and elsewhere (as in America and Sweden), have partaken rather of a see-saw motion, in which case the latest disturbance was very probably an upheaval of the lesser, and the lowering of the higher chain.

In addition to the many evidences of the action of ice in the northern parts of Europe which we have already mentioned, there occur here and there in some of these countries, what are wanting in Switzerland, deposits of marine fossil shells, which exhibit so arctic a character that they must have led the geologist to infer the former prevalence of a much colder climate, even had he not encountered so many accompanying signs of ice-action. The same marine shells demonstrate the submergence of large areas in Scandinavia and the British Isles, during the glacial cold.

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[1] Principles, 11th edit. vol. ii. p. 82.

A characteristic feature of the deposits under consideration in all these countries is the occurrence of large erratic blocks, and sometimes of moraine matter, in situations remote from lofty mountains, and separated from the nearest points where the parent rocks appear at the surface by great intervening valleys, or arms of the sea. We also often observe striæ and furrows, as in Norway, Sweden, and Scotland, which deviate from the direction which they ought to follow if they had been connected with the present line of drainage, and they, therefore, imply the prevalence of a very distinct condition of things at the time when the cold was most intense. The actual state of North Greenland seems to afford the best explanation of such abnormal glacial markings.

Greenland continental ice.—Greenland is a vast unexplored continent, buried under one continuous and colossal mass of ice that is always moving seaward, a very small part of it in an easterly direction, and all the rest westward, or towards Baffin's Bay. All the minor ridges and valleys are levelled and concealed under a general covering of snow, but here and there some steep mountains protrude abruptly from the icy slope, and a few superficial lines of stones or moraines are visible at certain seasons, when no snow has fallen for many months, and when evaporation, promoted by the wind and sun, has caused much of the upper snow to disappear. The height of this continent is unknown, but it must be very great, as the most elevated lands of the outskirts, which are described as comparatively low, attain altitudes of 4,000 to 6,000 feet. The icy slope gradually lowers itself towards the outskirts, and then terminates abruptly in a mass about 2,000 feet in thickness, the great discharge of ice taking place through certain large friths which, at their upper ends, are usually about four miles across. Down these friths the ice is protruded in huge masses, several miles wide, which continue their course—grating along the rocky bottom like ordinary glaciers long after they have reached the salt water. When at last they arrive at parts of Baffin's Bay deep enough to buoy up icebergs from 1,000 to 1,500 feet in vertical thickness, broken masses of them float off, carrying with them on their surface not only fine mud and sand but large stones. These fragments of rock are often polished and scored on one or more sides, and as the ice melts, they drop down to the bottom of the sea, where large quantities of mud are deposited, and this muddy bottom is inhabited by many mollusca.

Although the direction of the ice-streams in Greenland may coincide in the main with that which separate glaciers would take, yet the striation of the surface of the rocks of an ice-clad continent would, on the whole, differ considerably in its minor details from that which would be imprinted on rocks constituting a region of separate glaciers. For where there is a universal covering of ice there will be a general outward movement from the higher and more central regions towards the circumference and lower country, and this movement will be, to a certain extent, independent of the minor inequalities of hill and valley. The moving ice may sometimes cross even at right angles deep narrow ravines, or the crests of buried ridges, on which last it may afterwards seem strange to detect glacial striæ and polishing when the liquefaction of the snow and ice has taken place.

Rink mentions that in North Greenland, powerful springs of clayey water escape in winter from under the ice, where it descends to 'the outskirts,' and, where, as already stated, it is often 2,000 feet thick—a fact showing how much grinding action is going on upon the surface of the subjacent rocks. I also learn from Dr. Torell that there are large areas in the outskirts, now no longer covered with permanent snow or glaciers, which exhibit on their surface unmistakeable signs of ancient ice-action, so that, vast as is the power now exerted by ice in Greenland, it must once have operated on a still grander scale. The land, though now very elevated, may perhaps have been formerly much higher. It is well known that the south coast of Greenland from latitude 60° to about 70° N., has, for the last four centuries been sinking at the rate of several feet in a century. By this means a surface of rock, well scored and polished by ice, is now slowly subsiding beneath the sea, and is becoming strewed over, as the icebergs melt, with impalpable mud and smoothed and scratched stones. It is not precisely known how far north this downward movement extends.

Drift carried by icebergs.—An account was given so long ago as the year 1822, by Scoresby, of icebergs seen by him in the Arctic seas drifting along in latitudes 69° and 70° N., which rose above the surface from 100 to 200 feet, and some of which measured a mile in circumference. Many of them were loaded with beds of earth and rock, of such thickness that the weight was conjectured to be from 50,000 to 100,000 tons. A similar transportation of rocks is known to be in progress in the southern hemisphere, where boulders included in ice are far more frequent than in the north. One of these icebergs was encountered in 1839, in mid-ocean, in the antarctic regions, many hundred miles from any known land, sailing northwards, with a large erratic block firmly frozen into it. Many of them, carefully measured by the officers of the French exploring expedition of the Astrolabe, were between 100 and 225 feet high above water, and from two to five miles in length. Captain D'Urville ascertained one of them which he saw floating in the Southern Ocean to be 13 miles long and 100 feet high, with walls perfectly vertical. The submerged portions of such islands must, according to the weight of ice relatively to sea-water, be from six to eight times more considerable than the part which is visible, so that when they are once fairly set in motion, the mechanical force which they might exert against any obstacle standing in their way would be prodigious.

We learn, therefore, from a study both of the arctic and antarctic regions, that a great extent of land may be entirely covered throughout the whole year by snow and ice, from the summits of the loftiest mountains to the sea-coast, and may yet send down angular erratics to the ocean. We may also conclude that such land will become in the course of ages almost everywhere scored and polished like the rocks which underlie a glacier. The discharge of ice into the surrounding sea will take place principally through the main valleys, although these are hidden from our sight. Erratic blocks and moraine matter will be dispersed somewhat irregularly after reaching the sea, for not only will prevailing winds and marine currents govern the distribution of the drift, but the shape of the submerged area will have its influence; inasmuch as floating ice, laden with stones, will pass freely through deep water while it will run aground where there are reefs and shallows. Some icebergs in Baffin's Bay have been seen stranded on a bottom 1,000 or even 1,500 feet deep. In the course of ages such a sea-bed may become densely covered with transported matter, from which some of the adjoining greater depths may be free. If, as in West Greenland, the land is slowly sinking, a large extent of the bottom of the ocean will consist of rock polished and striated by land-ice, and then overspread by mud and boulders detached from melting bergs.

The mud, sand, and boulders thus let fall in still water must be exactly like the moraines of terrestrial glaciers, devoid of stratification and organic remains. But occasionally, on the outer side of such packs of stranded bergs, the waves and currents may cause the detached earthy and stony materials to be sorted according to size and weight before they reach the bottom, and to acquire a stratified arrangement.

I have already alluded (p. 150) to the large quantity of ice, containing great blocks of stone, which is sometimes seen floating far from land, in the southern or Antarctic seas. After the emergence, therefore, of such a sub-marine area, the superficial detritus will have no necessary relation to the hills, valleys, and river plains over which it will be scattered. Many a watershed may intervene between the starting-point of each erratic or pebble and its final resting-place, and the only means of discovering the country from which it took its departure will consist in a careful comparison of its mineral or fossil contents with those of the parent rocks.

CHAPTER XII.

PLEISTOCENE PERIOD, CONTINUED.—GLACIAL CONDITIONS, CONCLUDED.

Glaciation of Scandinavia and Russia—Glaciation of Scotland—Mammoth in Scotch till—Marine shells in Scotch glacial drift—Their Arctic character—Rarity of organic remains in glacial deposits—Contorted strata in drift—Glaciation of Wales, England, and Ireland—Marine shells of Moel Tryfaen—Erratics near Chichester—Glacial formations of North America—Many species of testacea and quadrupeds survived the glacial cold—Connection of the predominance of lakes with glacial action—Action of ice in preventing the silting up of lake-basins—Absence of lakes in the Caucasus—Equatorial lakes of Africa.

Glaciation of Scandinavia and Russia.—In large tracts of Norway and Sweden, where there have been no glaciers in historical times, the signs of ice-action have been traced as high as 6,000 feet above the level of the sea. These signs consist chiefly of polished and furrowed rock surfaces, of moraines and erratic blocks. The direction of the erratics, like that of the furrows, has usually been conformable to the course of the principal valleys; but the lines of both sometimes radiate outwards in all directions from the highest land, in a manner which is only explicable by the hypothesis above alluded to of a general envelope of continental ice, like that of Greenland (p. 149). Some of the far-transported blocks have been carried from the central parts of Scandinavia towards the Polar regions; others southwards to Denmark; some south-westwards, to the coast of Norfolk in England; others south-eastwards, to Germany, Poland, and Russia.

In the immediate neighbourhood of Upsala, in Sweden, I had observed, in 1834, a ridge of stratified sand and gravel, in the midst of which occurs a layer of marl, evidently formed originally at the bottom of the Baltic, and containing the mussel, cockle, and other marine shells of living species, intermixed with some proper to fresh water. The marine shells are all of dwarfish size, like those now inhabiting the brackish waters of the Baltic; and the marl, in which many of them are embedded, is now raised more than 100 feet above the level of the Gulf of Bothnia. *Upon the top of this ridge repose several huge erratics, consisting of gneiss for the most part unrounded, from*

9 to 16 feet in diameter, and which must have been brought into their present position since the time when the neighbouring gulf was already characterised by its peculiar fauna. Here, therefore, we have proof that the transport of erratics continued to take place, not merely when the sea was inhabited by the existing testacea but when the north of Europe had already assumed that remarkable feature of its physical geography, which separates the Baltic from the North Sea, and causes the Gulf of Bothnia to have only one-fourth of the saltness belonging to the ocean. In Denmark, also, recent shells have been found in stratified beds, closely associated with the boulder clay.

Glaciation of Scotland.—Mr. T. F. Jamieson, in 1858, adduced a great body of facts to prove that the Grampians once sent down glaciers from the central regions in all directions towards the sea. 'The glacial grooves,' he observed, 'radiate outwards from the central heights towards all points of the compass, although they do not always strictly conform to the actual shape and contour of the minor valleys and ridges.'

These facts and other characteristics of the Scotch drift lead us to the inference that when the glacial cold first set in, Scotland stood higher above the sea than at present, and was covered for the most part with snow and ice as Greenland is now. This sheet of land-ice sliding down to lower levels, ground down and polished the subjacent rocks, sweeping off nearly all superficial deposits of older date, and leaving only till and boulders in their place. To this continental state succeeded a period of depression and partial submergence. The sea advanced over the lower lands, and Scotland was converted into an archipelago, some marine sand with shells being spread over the bottom of the sea. On this sand a great mass of boulder clay usually quite devoid of fossils was accumulated. Lastly, the land re-emerged from the water, and, reaching a level somewhat above its present heights, became connected with the Continent of Europe, glaciers being formed once more in the higher regions, though the ice probably never regained its former extension.[1] After all these changes, there were some minor oscillations in the level of the land, on which, although they have had important geographical consequences, separating Ireland from England, for example, and England from the continent, we need not here enlarge.

Mammoth in Scotch Till.—Almost all remains of the terrestrial fauna of the continent which preceded the period of submergence have been lost; but a few patches of estuarine and freshwater formations escaped denudation by submergence. To these belong the peaty clay from which several mammoths' tusks and horns of reindeer were obtained at Kilmaurs in Ayrshire as long ago as 1816. Mr. Bryce in 1865 ascertained that the freshwater formation containing these fossils rests on carboniferous sandstone, and is covered, first by a bed of marine sand with arctic shells, and then with a great mass of till with glaciated boulders.[1] Still more recent explorations in the neighbourhood of Kilmaurs have shown that the freshwater formation contains the seed of the pond-weed *Potamogeton* and the aquatic Ranunculus ; and Mr. Young of the Glasgow Museum washed the mud adhering to the reindeer horns of Kilmaurs and that which filled the cracks of the associated elephants' tusks, and detected in these fossils (which had been in the Glasgow Museum for half a century) abundance of the same seeds.

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[1] Jamieson, Quart. Geol. Journ. 1860, vol. xvi. p. 370.

All doubts therefore as to the true position of the remains of the mammoth, a fossil so rare in Scotland, have been set at rest, and it serves to prove that part of the ancient continent sank beneath the sea at a period of great cold, as the shells of the overlying sand attest. The incumbent till or boulder-clay is about 40 feet thick, but it often attains much greater thickness in the same part of Scotland.

Marine shells of Scotch Drift.—The greatest height to which marine shells have yet been traced in this boulder-clay is at Airdrie in Lanarkshire, ten miles east of Glasgow, 524 feet above the level of the sea. At that spot they were found imbedded in stratified clays with till above and below them. There appears no doubt that the overlying deposit was true glacial till, as some boulders of granite were observed in it, which must have come from distances of sixty miles at the least.

Fig. 110.
Astarte borealis, Chem.;
(*A. arctica*, Möll.; *A. compressa*, Mont.)

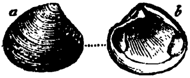
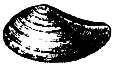


Fig. 111.
Leda lanceolata
(*oblonga*), Sow.



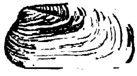


Fig. 112.
Saxicava rugosa,
Penn.

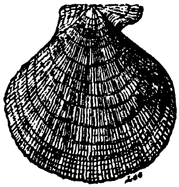


Fig. 113.
Pecten islandicus,
Möll.

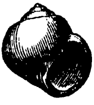


Fig. 114.
Natica clausa,
Bred.

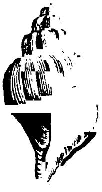


Fig. 115.
Trophon clathratum, Linné.

Northern shells common in the drift of the Clyde, in Scotland.

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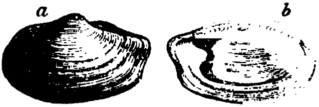
[1] Bryce, Quart. Geol. Journ. vol. xxi. p. 217. 1865.

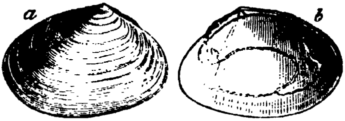
The shells above figured are only a few out of a large assemblage of living species, which, taken as a whole, bear testimony to conditions far more arctic than those now prevailing in the Scottish seas. But a group of marine shells, indicating a still greater ex cess of cold, has been brought to light since 1860 by the Rev. Thomas Brown, from glacial drift or clay on the borders of the estuaries of the Forth and Tay. This clay occurs at Elie in Fife, and at Errol in Perthshire ; and has already afforded about 35 shells, all of living species, and now inhabitants of arctic regions, such as *Leda truncata*, *Tellina proxima* (see figs. 116, 117), *Pecten Grœnlandicus*, *Crenella lævigata*, *Crenella nigra*, and others, some of them first brought by Captain Sir E. Parry from the coast of Melville Island, latitude 76° N. These were all identified in 1863 by Dr. Torell, who had just returned from a survey of the seas around Spitzbergen, where he had collected no less than 150 species of mollusca, living chiefly on a bottom of fine mud derived from the moraines of melting glaciers which there protrude into the sea. He informed me that the fossil fauna of this Scotch glacial deposit exhibits not only the species but also the peculiar varieties of mollusca now characteristic of very high latitudes. Their large size implies that they formerly enjoyed a colder, or, what was to them a more congenial climate, than that now prevailing in the latitude where the fossils occur. Marine shells have also been found in the glacial drift of Caithness and Aberdeenshire at heights of 250 feet, and in Banff of 350 feet, and stratified drift continuous with the above ascends to heights of 500 feet. Already 75 species are enumerated from Caithness and the same number from Aberdeenshire and Banff, and in both cases all but six are arctic species.

Fig. 116.



Leda truncata.
a. Exterior of left valve.
b. Interior of same.

Fig. 117.



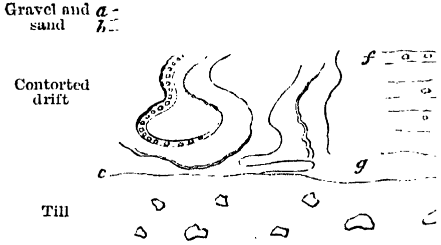
Tellina calcarea, Chem. (*Tellina proxima* Brown.)
a. Outside of left valve.
b. Interior of same.

I formerly suggested that the absence of all signs of organic life in the Scotch drift might be connected with the severity of the cold, and also in some places with the depth of the sea during the period of extreme submergence ; but my faith in such an hypothesis has been shaken by modern investigations, an exuberance of life having been observed both in arctic and antarctic seas of great depth, and where floating ice abounds. The difficulty moreover of accounting for the entire dearth of marine shells in till is removed when once we have adopted the theory of this boulder-clay being the product of land-ice. For glaciers coming down from a continental ice-sheet like that which covers Greenland, may fill friths many hundred feet below the sea-level, and even invade parts of a bay a thousand feet deep, before they find water enough to float off their terminal portions in the form of icebergs. In such a case till without marine shells may first accumulate, and then if the climate becomes warmer and the ice melts, a marine deposit may be superimposed on the till without any change of level being required.

Another curious phenomenon bearing on this subject was styled by the late Hugh Miller the 'striated pavements' of the boulder clay. Where portions of the till have been removed by the sea on the shores of the Forth, or in the interior by railway cuttings, the boulders embedded in what remains of the drift are seen to have been all subjected to a process of abrasion and striation, the striæ and furrows being parallel and persistent across them all, exactly as if a glacier or iceberg had passed over them and scored them in a manner similar to that so often undergone by the solid rocks below the glacial drift. It is possible, as Mr. Geikie conjectures, that this second striation of the boulders may be referable to floating ice.[1]

Contorted Strata in Drift.—In Scotland the till is often covered with stratified gravel, sand, and clay, the beds of which are sometimes horizontal and sometimes contorted for a thickness of several feet. Such contortions are not uncommon in Forfarshire, where I observed them, among other places, in a vertical cutting made in 1840 near the left bank of the South Esk, east

Fig. 118.



Section of contorted drift overlying till, seen on left bank of South Esk, near Cortachie, in 1840.

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[1] Geikie, Trans. Geol. Soc. Glasgow, vol. i. part 2, p. 68. 1863.

of the bridge of Cortachie. The convolutions of the beds of fine and coarse sand, gravel, and loam, extend through a thickness of no less than 25 feet vertical, or from *b* to *c*, fig. 115, the horizontal stratification being resumed very abruptly at a short distance, as to the right of *f*, *g*. The overlying coarse gravel and sand *a*, is in some places horizontal, in others it exhibits cross bedding, and does not partake of the disturbances which the strata *b*, *c*, have undergone. The underlying till is exposed for a depth of about 20 feet; and we may infer from sections in the neighbourhood that it is considerably thicker.

In some cases I have seen fragments of stratified clays and sands, bent in like manner, in the middle of a great mass of till. Mr. Trimmer has suggested, in explanation of such phenomena, the intercalation in the glacial period of large irregular masses of snow or ice between layers of sand and gravel. Some of the cliffs near Behring's Straits, in which the remains of elephants occur, consist of ice mixed with mud and stones; and Middendorf describes the occurrence in Siberia of masses of ice, found at various depths from the surface after digging through drift. Whenever the intercalation of snow and ice with drift, whether stratified or unstratified, has taken place, the melting of the ice will cause such a failure of support as may give rise to flexures, and sometimes to the most complicated foldings. But in many cases the strata may have been bent and deranged by the mechanical pressure of an advancing glacier, or by the sideway thrust of huge islands of ice running aground against sandbanks; in which case, the position of the beds forming the foundation of the banks may not be at all disturbed by the shock.

There are indeed many signs in Scotland of the action of floating ice, as might have been expected where proofs of submergence in the Glacial Period are not wanting. Among these are the occurrence of large erratic blocks, frequently in clusters at or near the tops of hills or ridges, places which may have formed islets or shallows in the sea where floating ice would mostly ground and discharge its cargo on melting. Glaciers or land-ice would, on the contrary, chiefly discharge their cargoes at the bottom of valleys. Traces of an earlier and independent glaciation have also been observed in some regions where the striation, apparently produced by ice proceeding from the north-west, is not explicable by the radiation of land-ice from a central mountainous region.[1]

Glaciation of Wales and England.—The mountains of

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[1] Milne Home, Trans. Royal Soc. Edinburgh, vol. xxv. 1868–9.

North Wales were recognised, in 1842, by Dr. Buckland, as having been an independent centre of the dispersion for erratics —great glaciers, long since extinct, having radiated from the Snowdonian heights in Carnarvonshire, through seven principal valleys towards as many points of the compass, carrying with them large stony fragments, and grooving the subjacent rocks in as many directions.

Besides this evidence of land glaciers, Mr. Trimmer had previously, in 1831, detected the signs of a great submergence in Wales in the Pleistocene period. He had observed stratified drift, from which he obtained about a dozen species of marine shells, near the summit of Moel Tryfaen, a hill 1,400 feet high on the south side of the Menai Straits. I had an opportunity of examining in the summer of 1863, in company with the Rev. W. S. Symonds, a long and deep cutting made through this drift by the Alexandra Mining Company in search of slates. At the top of the hill above-mentioned we saw a stratified mass of incoherent sand and gravel 35 feet thick, from which no less than 54 species of mollusca, besides three characteristic arctic varieties—in all 57 forms—have been obtained by Mr. Darbishire. They belong without exception to species still living in British or more northern seas; eleven of them being exclusively arctic, four common to the arctic and British seas, and a large proportion of the remainder having a northward range, or, if found at all in the southern seas of Britain, being comparatively less abundant. In the lowest beds of the drift were large heavy boulders of far-transported rocks, glacially polished and scratched on more than one side. Underneath the whole we saw the edges of vertical slates exposed to view; they were smoothed in places, but there was nowhere a sufficient exposure to enable us to decide whether it was the effect of glaciation or beach erosion. The whole deposit has much the appearance of an accumulation in shallow water or on a beach, and it probably acquired its thickness during the gradual subsidence of the coast—an hypothesis which would require us to ascribe to it a high antiquity, since we must allow time, first for its sinking, and then for its re-elevation.

The height reached by these fossil shells on Moel Tryfaen is no less than 1,300 feet—a most important fact when we consider how very few instances we have on record beyond the limits of Wales, whether in Europe or North America, of marine shells having been found in glacial drift at half the height above indicated. A marine molluscous fauna, however, agreeing in character with that of Moel Tryfaen and comprising as many species, was found by Mr. Prestwich, in 1862, at Vale

Royal near Macclesfield at an elevation between 1,100 and 1,200 feet and similar patches have been found at lesser heights in other places in central England.

Professor Ramsay[1] estimated the probable amount of submergence during some part of the glacial period at about 2,300 feet; for he was unable to distinguish the superficial sands and gravel which reached that high elevation from the drift which, at Moel Tryfaen and at lower points, contains shells of living species. The evidence of the marine origin of the highest drift is no doubt inconclusive in the absence of shells, so great is the resemblance of the gravel and sand of a sea beach and of a river's bed, when organic remains are wanting; but, on the other hand, when we consider the general rarity of shells in drift which we know to be of marine origin, we cannot suppose that, in the shelly sands of Moel Tryfaen, we have hit upon the exact uppermost limit of marine deposition, or, in other words, a precise measure of the submergence of the land beneath the sea during the glacial period.

We are gradually obtaining proofs of the larger part of England, north of a line drawn from the mouth of the Thames to the Bristol Channel, having been under the sea and traversed by floating ice since the commencement of the glacial epoch. Among recent observations illustrative of this point, I may allude to the discovery, by Mr. J. F. Bateman, at Mottram, east of Manchester, fifty miles from the sea, and at the height of 568 feet above its level, of till containing rounded and angular stones and marine shells, such as *Turritella communis, Purpura lapillus, Cardium edule,* and others, among which *Trophon clathratum* (= *Fusus Bamffius,*) though still surviving in North British seas, indicates a cold climate.[2]

Erratics near Chichester.—The most southern memorials of ice-action and of a Pleistocene fauna in Great Britain is on the coast of the county of Sussex, about 25 miles west of Brighton, and 10 south of Chichester. A marine deposit exposed between high and low tide occurs on both sides of the promontory called Selsea Bill, in which Mr. Godwin-Austen found thirty-eight species of shells, and the number has since been raised (1873) to a hundred and forty.

This assemblage is interesting because on the whole, while all the species are recent, they have a somewhat more southern aspect than those of the present British Channel. It is true that about forty of them range from British to high northern latitudes; but several of them, as, for example, *Rissoa cimex,*

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[1] Quart. Geol. Journ., 1852, vol. viii. p. 372.

[2] Cited by Binney, Proc. Manchester Phil. Soc. No. 3, 1862-5, p. 15.

Chiton siculus, *Lutraria rugosa* and *Pecten polymorphus*, which are abundant, are not known at present to range farther north than the coast of Portugal, and seem to indicate a warmer temperature than now prevails on the coast where we find them fossil. What renders this curious is the fact that the sandy loam in which they occur is overlaid by yellow clayey gravel with large erratic blocks which must have been drifted into their present position by ice when the climate had become much colder. These transported fragments of granite, syenite, and greenstone, as well as of Devonian and Silurian rocks, may have come from the coast of Normandy and Brittany, and are many of them of such large size that we must suppose them to have been drifted into their present site by coast-ice. I measured one of granite, at Pagham, 21 feet in circumference. In the gravel of this drift with erratics are a few littoral shells of living species, indicating an ancient coastline.

Glacial formations in North America.—In the western hemisphere, both in Canada and as far south as the 40th and even 38th parallel of latitude in the United States, we meet with a repetition of all the peculiarities which distinguish the European boulder formation. Fragments of rock have travelled for great distances, especially from north to south : the surface of the subjacent rock is smoothed, striated, and fluted ; unstratified mud or *till* containing boulders is associated with strata of loam, sand, and clay, usually devoid of fossils. Where shells are present, they are of species still living in northern seas, and not a few of them identical with those belonging to European drift, including most of those already figured, p. 156. The fauna also of the glacial epoch in North America is less rich in species than that now inhabiting the adjacent sea, whether in the Gulf of St. Lawrence, or off the shores of Maine, or in the Bay of Massachusetts.

The extension on the American continent of the range of erratics during the Pleistocene period to lower latitudes than they reached in Europe, agrees well with the present southward deflection of the isothermal lines, or rather the lines of equal winter temperature. It seems that formerly, as now, a more extreme climate and a more abundant supply of ice prevailed on the western side of the Atlantic. Another resemblance between the distribution of the drift fossils in Europe and North America has yet to be pointed out. In Canada and the United States, as in Europe, the marine shells are generally confined to very moderate elevations above the sea (between 100 and 700 feet), while the erratic blocks and the grooved and polished surfaces of rock extend to elevations of several thousand feet.

I have already mentioned that in Europe several quadrupeds of living, as well as extinct, species were common to pre-glacial and post-glacial times. In like manner there is reason to suppose that in North America much of the ancient mammalian fauna, together with nearly all the invertebrata, lived through the ages of intense cold. That in the United States the *Mastodon giganteus* was very abundant after the drift period, is evident from the fact that entire skeletons of this animal are met with in bogs and lacustrine deposits occupying hollows in the glacial drift. They sometimes occur in the bottom even of small ponds recently drained by the agriculturist for the sake of the shell-marl. In 1845 no less than six skeletons of the same species of Mastodon were found in Warren county, New Jersey, six feet below the surface, by a farmer who was digging out the rich mud from a small pond which he had drained. Five of these skeletons were lying together, and a large part of the bones crumbled to pieces as soon as they were exposed to the air.

It would be rash, however, to infer from such data that these quadrupeds were mired in *modern* times, unless we use that term strictly in a geological sense. I have shown that there is a fluviatile deposit in the valley of the Niagara, containing shells of the genera *Melania*, *Lymnea*, *Planorbis*, *Valvata*, *Cyclas*, *Unio*, *Helix*, &c., all of recent species. From this deposit the bones of the great Mastodon have been taken in a very perfect state. Yet the whole excavation of the ravine, for many miles below the Falls, has been slowly effected since that fluviatile deposit was thrown down. Other extinct animals accompany the *Mastodon giganteus* in the post-glacial deposits of the United States, and this taken with the fact that so few of the mollusca, even of the commencement of the cold period, differ from species now living is important, as refuting the hypothesis, for which some have contended, that the intensity of the glacial cold annihilated all the species in temperate and arctic latitudes.

Connection of the predominance of lakes with glacial action.—It was first pointed out by Professor Ramsay in 1862, that lakes are exceedingly numerous in those countries where erratics, striated blocks, and other signs of ice-action abound; and that they are comparatively rare in tropical and sub-tropical regions. Generally in countries where the winter cold is intense, such as Canada, Scandinavia, and Finland, even the plains and lowlands are thickly strewn with innumerable ponds and small lakes, together with some others of a larger size: while in more temperate regions, such as Great Britain, Central and Southern Europe, the United States, and New Zealand, lake districts occur in all such mountainous tracts as can be proved to have been glaciated in times comparatively modern or since the geographical configuration of the surface bore a considerable resemblance to that now prevailing. In the same countries, beyond the glaciated regions, lakes abruptly cease, and in warmer and tropical countries are either entirely absent or consist, as in equatorial Africa, of large sheets of water unaccompanied as far as we yet know by numerous smaller ponds and tarns.

The southern limits of the lake districts of the Northern Hemisphere are found at about 40° N. latitude on the American continent, and about 50° in Europe, or where the Alps intervene four degrees farther south. A large proportion of the smaller lakes are dammed up at their lower end by barriers of unstratified drift, having the exact character of the moraines of glaciers, and are termed by geologists 'morainic' but some of them are true rock-basins and would hold water even if all the loose-drift now resting on their margins were removed; and however difficult it may be to explain the manner in which they have been formed, we cannot suppose that they have each of them been due to a special subsidence of the rocks where the cavities filled with water now occur.

In a paper read before the Geological Society of London in 1862, Professor Ramsay maintained that the first formation of most existing lakes took place during the glacial epoch, and was due, not to elevation or subsidence, but to actual erosion of their basins by glaciers. M. Mortillet in the same year advanced the theory that after the Alpine lake-basins had been filled up with loose fluviatile deposits, they were re-excavated by the great glaciers which passed down the valleys at the time of the greatest cold, a doctrine which would attribute to moving ice almost as great a capacity of erosion as that which assumed that the original basins were scooped out of solid rock by glaciers. The mere geographical distribution of lakes suggests the connection of their origin with the abundance of ice during a former excess of cold, but how far the erosive action of moving ice has been the principal cause of lake-basins, is a question still open to discussion.

The lakes of Switzerland and the north of Italy are some of them twenty and thirty miles in length, and so deep that their bottoms are in some cases from 1,000 to 2,000 feet beneath the level of the sea. It is admitted on all hands that they were once filled with ice, and as the existing glaciers polish and grind down as before stated the surface of the rocks, we are prepared to find that every lake-basin in countries once covered by ice should bear the marks of superficial glaciation, and also that the ice during its advance and retreat should have left behind it much transported matter as well as some evidence of its having enlarged the pre-existing cavity. But much more than this is demanded by the advocates of glacial erosion. They suggest that as the old extinct glaciers were several thousand feet thick, they were able in some places gradually to scoop out of the solid rock cavities twenty or thirty miles in length, and as in the case of Lago Maggiore from a thousand to two thousand six hundred feet below the previous level of the river-channel, and also that the ice had the power to remove from the cavity formed by its grinding action all the materials of the missing rocks. A constant supply, it is argued, of fine mud issues from the termination of every glacier in the stream which is produced by the melting of the ice, and this result of friction is exhibited both during winter and summer, affording evidence of the continual deepening and widening of the valleys through which glaciers pass. As the fine mud is carried away by a river from the deep pool which is formed from the base of every cataract, so it seems to be imagined that lake-basins may be gradually emptied of the mud formed by abrasion during the glacial period.

I am by no means disposed to object to this theory on the ground of the insufficiency of the time during which the extreme cold endured, but we must carefully consider whether that same time is not so vast as to make it probable that other forces, besides the motion of glaciers, must have co-operated in converting some parts of the ancient valley courses into lake-basins. They who have formed the most exalted conceptions of the erosive energy of moving ice do not deny that during the period termed 'Glacial' there have been movements of the earth's crust sufficient to produce changes of level in Europe amounting even in England to 1,400 feet, as in Moel Tryfaen. M. Charpentier, indeed, attributed some of the principal variations of climate in Switzerland, during the glacial period, to a diminution in altitude of the central Alps to the extent of 3,000 feet, and Swiss geologists have long been accustomed to attribute their lake-basins, in part, to those convulsions by which the shape and course of the valleys may have been modified. They commonly observe that in those regions where the glaciers have retreated or melted back at their lower end during a succession of warm seasons, the ground on which they had previously reposed, being uncovered, consists of convex or dome-shaped protuberances polished and striated. As a rule, there is an absence of cavities or rock-basins holding water. If inequalities of movement such as those witnessed in New Zealand in 1855, and above alluded to (p. 149), are part of the regular course of nature, and have governed the movements of the earth's crust in ancient as well as in modern time, we cannot doubt that they must have influenced the formation of lakes, more especially if we can show that the glacial period, or at least some part of it, was sufficiently modern to reach down to the era of the living species of mollusca. That this was the case is sufficiently proved by the occurrence of marine shells in the West of England at the height of 1,100 feet near Macclesfield, and of 1,400 on Moel Tryfaen, eighty miles distant; these fossil shells being species still living, though implying a more northern fauna than that of corresponding latitudes at the present period.

But, it is asked, if such inequality of movement can have contributed towards the production of lake-basins, does it not leave unexplained the comparative rarity of lakes in tropical and subtropical countries? In reply to this question it may be observed that in our endeavour to estimate the effects of subterranean movements in modifying the superficial geography of a country we must remember that each convulsion effects a very slight change. If it interferes with the drainage, whether by raising the lower or sinking the higher portion of a hydrographical basin, the upheaval or depression will only amount to a few feet at a time, and there may be an interval of years or centuries before any further movement takes place in the same region. In the meantime an incipient lake if produced may be filled up with sediment, and the recently-formed barrier will then be cut through by the river, whereas in a country where glacial conditions prevail no such obliteration of the temporary lake-basin would take place: for however deep it became by repeated sinking of the upper or rising of the lower extremity, being always filled with ice it might remain, throughout the greater part of its extent, free from sediment or drift until the ice melted at the close of the glacial period.

One of the most serious objections to the exclusive origin by ice-erosion of wide and deep lake-basins arises from their capricious distribution, as for example in Piedmont, both to the eastward and westward of Turin where great lakes are wanting,[1] although some of the largest extinct glaciers descending from Mont Blanc and Monte Rosa came down from the Alps leaving their gigantic moraines in the low country. Here, therefore, we might have expected to find lakes of the first magnitude rivalling the contiguous Lago Maggiore in importance.

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[1] Antiquity of Man, p. 361.

A still more striking illustration of the same absence of lakes where large glaciers abound is said to be afforded by the Caucasus, a chain more than 300 miles long, and the loftiest peaks of which attain heights from 16,000 to 18,000 feet. This greatest altitude is reached by Elbruz, a mountain in lat. 43° N., three degrees south of Mont Blanc, but on the other hand 3,000 feet higher. The present Caucasian glaciers are equal or superior in dimensions to those of Switzerland, and like them give rise occasionally to temporary lakes by obstructing the course of rivers, and causing great floods when the icy barriers give way. Mr. Freshfield, a careful observer, writing in 1869, says:[1] 'A total absence of lakes, on both sides of the chains, is the most marked feature. Not only are there no great subalpine sheets of water, like Como or Geneva, but mountain tarns, such as the Dauben See, on the Gemmi, or the Klonthal See, near Glarus, are equally wanting. Mr. Freshfield, however, does not tell us whether in the Caucasus, as in the valley of the Rhone above the Lake of Geneva, there are not some alluvial flats which may indicate filled-up lakes containing gravel and sand of unknown thickness.

To pass to another region, it seems safe to assume that the chain of lakes, of which the Albert Nyanza forms one in equatorial Africa, was due to causes other than glacial. Yet if we could imagine a glacial period to visit that region filling the lakes with ice and scoring the rocks which form their sides and bottoms, we should be unable to decide how much the capacity of the basins had been enlarged and the surface modified by glacial erosion. Lago Maggiore and Lake Superior may have had a similar origin, although the present basins of both of them afford abundant superficial markings due to ice-action.

But to whatever combination of causes we attribute the great Alpine lakes one thing is clear, namely, that they are, geologically speaking, of modern origin. Every one must admit that the upper valley of the Rhone has been chiefly caused by fluviatile denudation, and it is obvious that the quantity of matter removed from that valley previous to the glacial period would have been amply sufficient to fill up with sediment the basin of the Lake of Geneva, supposing it to have been in existence, even if its capacity had been many times greater than it is now.[2]

On the whole, although it appears to me, in accordance with the views of Prof. Ramsay, M. Mortillet, Mr. Geikie, and others, that many mountain tarns and small lakes are situated in rock-basins, their waters not being dammed up simply by moraines, but due to the action of ice in a manner not yet well understood; still when it is a question of the origin of larger and deeper lakes, like those of Switzerland or the north of Italy, or inland freshwater seas, like those of Canada, it will be found that ice erosion has played a subordinate part in comparison with those movements by which changes of level in the earth's crust are gradually brought about.

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[1] Travels in Central Caucasus, 1869, p. 452.

[2] See Principles, vol. i. p. 416, 11th ed. 1872.

TERTIARY OR CAINOZOIC PERIOD.

CHAPTER XIII.

PLIOCENE PERIOD.

Glacial formations of Pliocene age—Bridlington beds—Glacial drifts of Ireland—Drift of Norfolk cliffs—Cromer forest-bed—Aldeby and Chillesford beds—Norwich Crag—Older Pliocene strata—Red Crag of Suffolk—Coprolitic bed of Red Crag—White or Coralline Crag—Relative age, origin, and climate of the Crag deposits—Antwerp Crag—Newer Pliocene strata of Sicily—Newer Pliocene strata of the Upper Val d'Arno—Older Pliocene of Italy—Subapennine strata—Older Pliocene flora of Italy.

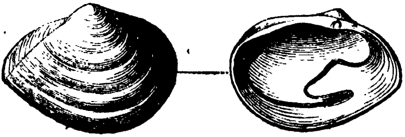
It will be seen in the description given in the last chapter of the Pleistocene formations of the British Isles that they comprise a large proportion of those commonly termed glacial, characterised by shells which, although referable to living species, usually indicate a colder climate than that now belonging to the latitudes where they occur fossil. But in parts of England, more especially in Yorkshire, Norfolk, and Suffolk, there are superficial formations of clay with glaciated boulders, and of sand and pebbles, containing occasional, though rare, patches of shells, in which the marine fauna begins to depart from that now inhabiting the neighbouring sea, and to resemble that of the crag presently to be described. It comprises some species of mollusca not yet known as living, as well as extinct varieties of others, entitling us to class them as Newer Pliocene, although belonging to the close of that period and chronologically on the verge of the later or Pleistocene epoch.

Bridlington drift.—To the latest part of this era belong certain deposits in the well-known locality of Bridlington, near the mouth of the Humber, in Yorkshire, lat. 54° N., where about 59 species or well-marked varieties of shells have been found on the coast, near the sea-level, in a thin bed of sand resting on glacial clay with much chalk débris, and covered by a deposit of purple clay with glaciated boulders. More than a third of these are now inhabitants of arctic regions, unknown to the British seas; several are British and Arctic, and only 10 belong to those species which range south of our British seas. Five species or well-marked varieties are not known living, namely, *Trophon Leckenbyi*, *Pleurotoma Dowsoni*, *P. robusta*, *Nucula Cobboldiæ*, and *Tellina obliqua*, fig. 123, p. 175. Mr. Searles Wood inclines to consider *Nucula Cobboldiæ*, fig. 122, p. 175, now absent from the European seas and the Atlantic, as specifically distinct from a closely-allied shell now living in the seas surrounding Vancouver's Island, which some conchologists regard as a variety. *Tellina obliqua* also approaches very near to a shell now living in Japan.

Glacial drift of Ireland.—Marine drift containing the last-mentioned *Nucula* and other glacial shells reaches a height of from 1,000 to 1,200 feet near the Three Rock Mountain, south-east of Dublin, and they are common in the county of Wexford, south of Dublin. More than 80 species have already been obtained from this formation. The great elevation at which these shells occur, and the still greater height to which the surface of the rocks in the mountainous regions of Ireland has been smoothed and striated by ice-action, have led geologists to the opinion that that island, like the greater part of England and Scotland, after having been united with the continent of Europe, from whence it received the plants and animals now inhabiting it, was in great part submerged. The conversion of this and other parts of Great Britain into an archipelago was followed by a re-elevation of land and a second continental period. After all these changes the final separation of Ireland from Great Britain took place, and this event has been supposed to have preceded the opening of the Straits of Dover.[1]

Drift of Norfolk and Suffolk cliffs.—There are deposits of boulder-clay, till, and sand in these cliffs principally made up of the waste of white chalk and flints which, in the opinion of Messrs. Searles Wood, jun., and Harmer, are older than the Bridlington drift. All the shells contained in them, with the exception of *Tellina balthica, Trophon mediglacialis*, and *T. Billockbiensis*, are common either to the Norwich or Red Crag. *Tellina balthica* (*T. solidula*), fig. 119, which abounds here, is found fossil at Bridlington, and is living in our British seas, but it is wanting in all the formations, even the newest,

Fig. 119.



Tellina balthica (*T. solidula*).

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[1] See Antiquity of Man, chap. xiv.

afterwards to be described as Crag. As the greater part of these drifts are barren of organic remains, their classification is at present a matter of great uncertainty; but, as an aid to the student, I give a table drawn up for the last edition of the 'Antiquity of Man' (1873), showing as nearly as possible their relative position.

Glacial and Post-Glacial Formations succeeding the Cromer Forest-Bed.

	Marine Deposits	Freshwater and Terrestrial Deposits
PLEISTOCENE	. . . . . .	Hoxne freshwater deposit, with Paleolithic implements, and Mundesley beds with fish-scales, insects, &c.
NEWER PLIOCENE	UPPER GLACIAL: Bridlington Beds Chalky Boulder Clay	
	MID-GLACIAL: Mid-Glacial Sands	
	LOWER GLACIAL: Contorted Drift Till of the Cromer Cliffs Pebbly Beds of Bure Valley and Westleton	Lignite layers, with arctic plants, *Salix Polaris*, and *Hypnum turgescens*.
	WEYBOURNE SANDS[1] .	Cromer Forest-Bed, with *Elephas meridionalis* and other extinct and living mammalia.
	CHILLESFORD AND NORWICH CRAG	

The main portion of these drifts can nowhere be so advantageously studied as on the coast between Happisburgh and Weybourne, and between Lowestoft and Yarmouth. Here we may see them in vertical cliffs sometimes 200 feet and more in height, exposed for a distance of many miles, at the base of part of which the chalk with flints crops out in nearly horizontal strata. Between Happisburgh and Weybourne the till is often strangely contorted, and envelopes huge masses or erratics of chalk with layers of vertical flint. I measured one of these fragments in 1839 at Sherringham, and found it to be eighty feet in its longest diameter.[1] It has been since entirely removed by the waves of the sea. In the floor of the chalk beneath it the layers of flint were horizontal. Such erratics have evidently been moved bodily from their original site, probably by the same glacial action which has polished and striated some of the accompanying granitic and other boulders, occasionally six feet in diameter, which are imbedded in the drift.

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[1] Mr. Searles Wood, jun., and Mr. Harmer, who have worked out the relations of these beds, place them, on account of the occurrence of *Tellina balthica*, at the base of the Lower Glacial; but they are so closely allied with the Norwich Crag, that it seems to me safer to keep them as an intermediate formation—as I did in previous editions.

Cromer Forest-bed.—Intervening between these glacial formations and the subjacent chalk lies what has been called the Cromer Forest-bed. This buried forest has been traced from Cromer to near Kessingland, a distance of more than forty miles, being exposed at certain seasons between high and low water mark. It is the remains of an old land and estuarine deposit, containing the submerged stumps of trees, which I saw in 1830 standing erect with their roots in the ancient soil. Associated with the stumps and overlying them, are lignite beds with freshwater shells of recent species, and laminated clay without fossils. Through the lignite and forest-bed are scattered cones of the Scotch and spruce firs with the seeds of recent plants, and the bones of at least twenty species of terrestrial mammalia. Among these are two species of elephant, *E. meridionalis*, Nesti, and *E. antiquus*, the former found in the Newer Pliocene beds of the Val d'Arno, near Florence. In the same bed occur *Hippopotamus major*, *Rhinoceros etruscus*, both of them also Val d'Arno species, many species of deer considered by Mr. Boyd Dawkins to be characteristic of warmer countries, and also a horse, beaver, and field-mouse. Half of these mammalia are extinct, and the rest still survive in Europe. The vegetation taken alone does not imply a temperature higher than that now prevailing in the British Isles. There must have been a subsidence of the forest to the amount of 400 or 500 feet, and a re-elevation of the same to an equal extent, in order to allow the ancient surface of the chalk or covering of soil, on which the forest grew, to be first covered with several hundred feet of drift, and then upheaved so that the trees should reach their present level. Although the relative antiquity of the forest-bed to the overlying glacial till is clear, there is some difference of opinion as to its relation to the crag presently to be described.

Chillesford and Aldeby beds.—It is in the counties of Norfolk, Suffolk, and Essex, that we obtain our most valuable information respecting the British Pliocene strata, whether newer or older. They have received in those counties the provincial name of 'Crag,' applied particularly to masses of shelly sand which have long been used in agriculture to fertilise soils deficient in calcareous matter. At Chillesford, between Woodbridge and Aldborough, in Suffolk, and Aldeby, near Beccles, in the same county, there occur stratified deposits, older than any of the preceding drifts of Yorkshire, Norfolk, and Suffolk. They are composed at both localities of sands and laminated clays, with much mica, forming horizontal beds about twenty feet thick. Messrs. Prestwich and Searles Wood, senior, when first describing these beds, considered that the shells indicated on the whole a colder climate than the Red Crag; but Mr. Wood (as explained p. 184) now regards the Red Crag as not all of one age, and finds that the fauna of the newer parts of it in some places, as at Butley and Boyton, indicates a cold climate, similar to that of the Chillesford and Aldeby beds. In the upper part of the laminated clays at Chillesford a skeleton of a whale was found associated with casts of the characteristic shells, *Nucula Cobboldiæ* and *Tellina obliqua*, already referred to as no longer inhabiting our seas, and as being extinct varieties if not species. The same shells occur in a perfect state in the lower part of the formation. *Natica helicoides* (fig. 120) is an example of a species formerly known only as fossil, but which has now been found living in our seas.

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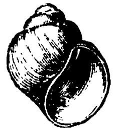
[1] See a paper by the Author, Philosophical Magazine, No. 104. May, 1840.

Fig. 120.

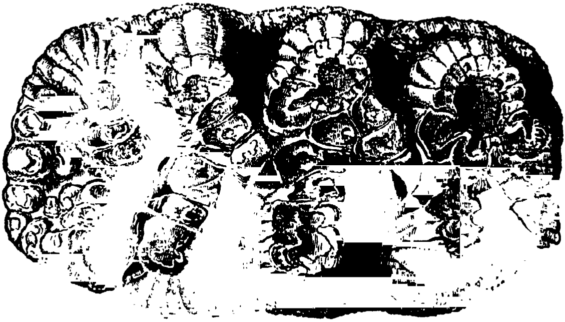


Natica helicoides, Johnston.

At Aldeby, Messrs. Crowfoot and Dowson have now obtained 66 species of mollusca, comprising the Chillesford species and some others. Of these about nine-tenths are recent. They are in a perfect state, clearly indicating a cold climate, as two-thirds of them are now met with in arctic regions. As a rule, the lamellibranchiate molluscs have both valves united, and many of them, such as *Mya arenaria*, stand with the siphonal end upwards, as when in a living state. *Tellina balthica*, before mentioned (fig. 119) as so characteristic of the glacial beds, including the drift of Bridlington, has not yet been found in deposits of Chillesford and Aldeby age, whether at Sudbourn, Easton Bavent, Horstead, Coltishall, Burgh, or where they overlie the Norwich Crag proper at Bramerton and Thorpe.

Norwich or Fluvio-marine Crag.—The Norwich Crag is chiefly seen in the neighbourhood of Norwich, and consists of beds of incoherent sand, loam, and gravel, which are exposed to view on both banks of the Yare, as at Bramerton and Thorpe. As they contain a mixture of marine, land, and freshwater shells, with bones of fish and mammalia, it is clear that these beds have been accumulated at the bottom of a sea near the mouth of a river. They form patches rarely exceeding twenty feet in thickness, resting on white chalk. At their junction with the chalk there invariably intervenes a bed called the 'Stone-bed,' composed of unrolled chalk flints, commonly of large size, mingled with the remains of a land fauna, comprising *Mastodon arvernensis*, *Elephas meridionalis*, and an extinct species of deer. The mastodon, which is a species characteristic of the Pliocene strata of Italy and France, is the most abundant fossil, and one not found in the Cromer forest before mentioned. When these flints, probably long exposed in the atmosphere, became submerged, they were covered with barnacles, and the surface of the chalk became perforated by the *Pholas crispata*, each fossil shell still remaining at the bottom of its cylindrical cavity, now filled up with loose sand from the incumbent crag. This species of Pholas still exists, and drills the rocks between high and low water on the British coast. The name of 'Fluvio-marine' has often been given to this formation, as no less than twenty species of land and freshwater shells have been found in it. They are all of living species; at least only one univalve, a *Paludina*, has any, and that a very doubtful, claim to be regarded as extinct.

Fig. 121.



Mastodon arvernensis, third milk molar, left side, upper jaw; grinding surface, natural size. Norwich Crag, Postwick, also found in Red Crag, see p. 178.

Of the marine shells, 112 in number, about 17 per cent. are extinct, according to the latest estimate given by Mr. Searles Wood in his Supplement to the Crag Mollusca;[1] but, for reasons presently to be mentioned, this percentage must be regarded only as provisional. It must also be borne in mind that the proportion of recent shells would be augmented if the uppermost beds at Bramerton, near Norwich, which belong to the most modern or Chillesford division of the Crag, had been included, as they were formerly, by Mr. Woodward and myself, in the Norwich series. Some of the arctic shells, which form so large a proportion in the Chillesford and Aldeby beds, are more rare in the Norwich Crag, though many northern species—such as *Rhynchonella psittacea*, *Scalaria Grænlandica*, *Astarte borealis*, *Panopæa norvegica*, and others—still occur. The *Nucula Cobboldiæ* and *Tellina obliqua*, figs. 122 and 123, before mentioned, p. 170, are frequent in these beds, as are also *Littorina littorea*, *Cardium edule*, and *Turritella communis*, of our seas, proving the littoral origin of the beds.

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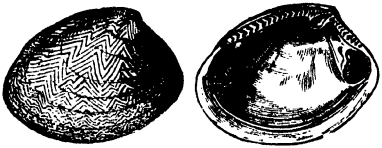
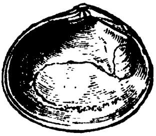
[1] Paleontographical Society, 1873.

Fig. 122.



Nucula Cobboldiæ.

Fig. 123.



Tellina obliqua.

OLDER PLIOCENE STRATA.

Red Crag.—Among the English Pliocene beds the next in antiquity is the Red Crag, which often rests immediately on the London clay, as in the county of Essex, illustrated in the accompanying diagram.

It is chiefly in the county of Suffolk that it is found, rarely exceeding twenty feet in thickness, and sometimes overlying another Pliocene deposit, the Coralline Crag, to be mentioned in the sequel. It has yielded—exclusive of 87 species regarded by Mr. Wood as derivative—248 species of mollusca, of which 69, or 27 per cent., are extinct. Thus, apart from its order of superposition, its greater antiquity as a whole than the Norwich and its still greater antiquity than the glacial beds already

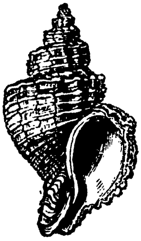
Fig. 124.

Red Crag. London Clay. Chalk.

described, is proved by the greater departure of its fauna from that of our seas. It may also be observed that in most of the deposits of this Red Crag, the northern forms of the Norwich Crag, and of such glacial formations as Bridlington, are less numerous, while those having a more southern aspect begin to make their appearance. Both the quartzose sand, of which it chiefly consists, and the included shells, are most commonly distinguished by a deep ferruginous or ochreous colour; whence its name. The shells are often rolled, sometimes comminuted, and the beds have much the appearance of having been shifting sandbanks, like those now forming on the Dogger-bank, in the sea, sixty miles east of the coast of Northumberland. Cross stratification is almost always observable, the planes of the strata being sometimes directed towards one point of the compass, sometimes to the opposite, in beds immediately overlying. That such a structure is not deceptive or due to any subsequent concretionary rearrangement of particles, or to mere bands of colour produced by the iron, is proved by each bed being made up of flat pieces of shell which lie parallel to the planes of the smaller strata.

It has long been suspected that the different patches of Red Crag are not all of the same age, although their chronological relation cannot always be decided by superposition. Separate masses are characterised by shells specifically distinct or greatly varying in relative abundance, in a manner implying that the deposits containing them were separated by intervals of time. At Butley, Tunstall, Sudbourn, and in the Red Crag of Chillesford, the mollusca appear to assume their most modern aspect, and the climate was colder than when the earliest deposits of the same period were formed. At Butley is found *Nucula Cobboldiæ*, so common in the Norwich and certain glacial beds, but unknown in the older parts of the Red Crag. On the other hand, at Walton-on-the-Naze, in Essex, we seem to have an exhibition of the oldest phase of the Red Crag, in which the percentage of extinct forms is almost as great as in the Coralline Crag; and where *Purpura tetragona* (fig. 125) is very abundant. The Walton Crag also indicates a warmer climate, both by the absence of many characteristic arctic shells that are common in the newer portions of the Red Crag, and by a greater proportion of Mediterranean species. *Voluta Lamberti* (see figs. 126 and 127), an extinct species, which seems to have flourished chiefly in the antecedent Coral-

Fig. 125.

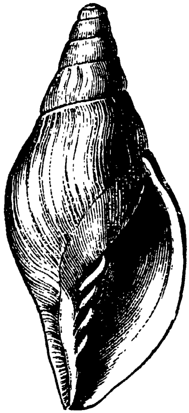


Purpura tetragona, Sow.; nat. size.

line Crag period, is still represented here by individuals of every age. A form closely allied to this Crag species, *Voluta Junonia*, Chem., was dredged up in 1860 from a depth of 250 fathoms in the Gulf-stream off the American coast.[1]

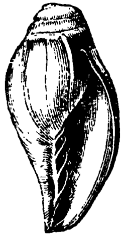
The reversed whelk (fig. 128) is common at Walton, where the dextral form of that shell is unknown. Here also specimens of lamellibranchiate molluscs are sometimes found with both the valves united, showing that they belonged to this sea of the Upper Crag, and were not washed in from an older bed, such as the Coralline, in which case the ligament would not have held together the valves in strata so often showing signs of the boisterous action of the waves. Such specimens of united valves are, however, rare. Mr. Searles Wood, after a most assiduous search, has only detected thirteen species in this perfect condition, and among these *Mactra ovalis* alone is common.

Fig. 126.



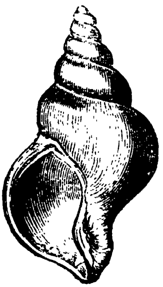
V. Lamberti, Sow. Variety characteristic of Suffolk Crag. Pliocene.

Fig. 127.



Voluta Lamberti, young individ., Cor. and Red Crag.

Fig. 128.



Trophon antiquum, Müll. (*Fusus contrarius*), half nat. size.

At and near the base of the Red Crag is a loose bed of brown nodules, first noticed by Professor Henslow as containing a large percentage of earthy phosphates. This bed of coprolites (as it is called, because they were originally supposed to be the fæces of animals) does not always occur at one level, but is generally in largest quantity at the junction of the Crag and the underlying formation. In thickness it usually varies from six to eighteen inches, and in some rare cases amounts to many feet. It has been much used in agriculture for manure, as not only the nodules, but many of the separate bones associated with them, are largely impregnated with phosphate of lime, of which there is sometimes as much as 60 per cent. They are not unfrequently covered with barnacles, showing that they were not formed as concretions in the stratum where they now lie buried, but had been previously consolidated. Organic remains from many of the older formations are included in these beds. The teeth of the Pliocene *Mastodon arvernensis* occur. From the wreck of Miocene deposits are found remains of *Rhinoceros Schleiermacheri*, *Tapirus priscus*, *Hipparion* (a quadruped of the horse family), the antlers of a stag, *Cervus anoceros*, and a large portion of the skull of a marine animal of the genus *Halitherium* lately recognised by Mr. Flower in the collection of the Rev. H. Canham of Waldringfield, and named by him *H. Canhami*. The specimen nearly allied to *H. Schinzi*, Kaup, of the Miocene of the Mayence basin, a form now represented by the Manatee or sea-cow and the Dugong.

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[1] Louis Agassiz, Bulltn. of Museum of Comparative Zoology, 1869, p. 263.

The phosphatic nodules often include fossil crustacea and fishes from the Eocene London clay, together with the teeth of gigantic sharks and the ear-bones of whales. Organic remains also of the older chalk and lias are met with, showing how great must have been the denudation of previous formations during the Pliocene period. As the older White Crag, presently to be mentioned, contains similar phosphatic nodules near its base, those of the Red Crag may be partly derived from this source.

White or Coralline Crag.—The lower or Coralline Crag is of very limited extent, ranging over an area about twenty miles in length, and three or four in breadth, between the rivers Stour and Alde, in Suffolk. It is generally calcareous and marly—often a mass of comminuted shells, and the remains of polyzoa (or bryozoa),[1] passing occasionally into a soft building-stone. At Sudbourn and Gedgave, near Orford, this building stone has been largely quarried. At some places in the neighbourhood the softer mass is divided by thin flags of hard limestone, and polyzoa placed in the upright position in which they grew. From the abundance of these coralloid mollusca the lowest or White Crag obtained its popular name of Coralline Crag; but true corals, as now defined, or zoantharia, are very rare in this formation.

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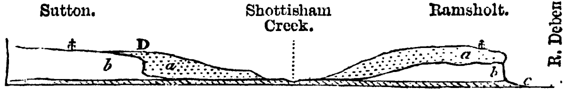
[1] Ehrenberg proposed in 1831 the term *Bryozoum*, or 'Moss-animal,' for the molluscous or ascidian form of polyp, characterised by having two openings to the digestive sack, as in *Eschara*, *Flustra*, *Retepora*, and other zoophytes popularly included in the corals, but now classed by naturalists as mollusca. The term *Polyzoum*, synonymous with *Bryozoum*, was, however, proposed in the previous year, 1830, by Mr. J. V. Thompson.

The Coralline Crag rarely, if ever, attains a thickness of thirty feet in any one section. Mr. Prestwich, who has thrown more light than any other writer on the geology of the Crag, imagines that if the beds found at different localities were united in the probable order of their succession, they might exceed eighty feet in thickness;[1] but Mr. Searles Wood does not believe in the possibility of establishing such a chronological succession by aid of the organic remains, and questions whether proof could be obtained of so great a thickness. I was unable to come to any satisfactory opinion on the subject, although at Orford, especially at Gedgrave, in the neighbourhood of that place, I saw many sections in pits, where this Crag is cut through. These pits are so unconnected, and of such limited extent, that no continuous section of any length can be obtained, so that speculations as to the thickness of the whole deposit must be very vague. At the base of the formation at Sutton a bed of phosphatic nodules, very similar to that before alluded to in the Red Crag, with remains of mammalia, has been met with.

Whenever the Red and Coralline Crag occur in the same district, the Red Crag lies uppermost; and, in some cases, as in the section represented in fig. 129, which I had an opportunity of seeing exposed to view in 1839, it is clear that the older deposit or Coralline Crag *b* had suffered denudation, before the newer formation *a* was thrown down upon it. At D there was not only seen a distinct cliff, eight or ten feet high, of Coralline Crag, running in a direction N.E. and S.W., against which the Red Crag abuts with its horizontal layers, but this cliff occasionally overhangs. The rock composing it is drilled everywhere by *Pholades*, the holes which they perforated having been afterwards filled with sand, and covered over when the newer beds were thrown down. The older formation is shown by its fossils to have accumulated in a deeper sea, and contains very few of those littoral forms such as the limpet, *Patella*, found

Fig. 129.



Section near Woodbridge, in Suffolk.

a. Red Crag. *b*. Coralline Crag. *c*. London Clay.

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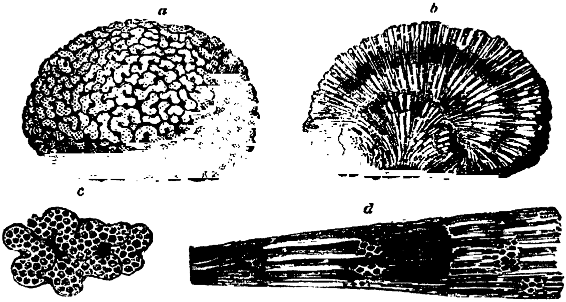
[1] Quart. Geol. Journ., vol. xxvii. p. 325, 1871.

in the Red Crag. So great an amount of denudation could scarcely have taken place, in such incoherent materials, without some of the fossils of the inferior beds becoming mixed up with the overlying Red Crag, so that considerable difficulty must be occasionally experienced by the palæontologist in deciding which species belong severally to each group or to both.

Fig. 130.

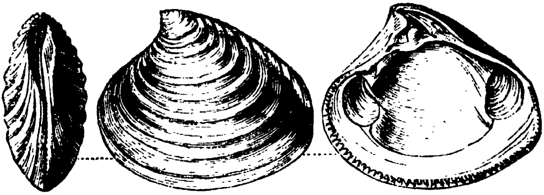


Fascicularia aurantium, Milne Edwards. Family, *Tubuliporidæ*, of same author. Polyzoan of extinct genus, from the inferior or Coralline Crag, Suffolk.

a. Exterior. *b*. Vertical section of interior. *c*. Portion of exterior magnified. *d*. Portion of interior magnified, showing that it is made up of long, thin, straight tubes, united in conical bundles.

Mr. Searles Wood estimates the total number of marine testaceous mollusca of the Coralline Crag at 396, of which 144 are not known as living, being in the proportion of 36 per cent. extinct. No less than 130 species of polyzoa have been found in the Coralline Crag, some belonging to genera believed to be now extinct, and of a very peculiar structure; as, for example, that represented in fig. 130, which is one of several species having a globular form. Among the testacea

Fig. 131.

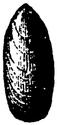


Astarte Omalii, Laj.; species common to Upper and Lower Crag.

the genus *Astarte* (see fig. 131) is largely represented, no less than fourteen species being known, and many of these being rich in individuals. There is an absence of genera peculiar to hot climates, such as *Conus*, *Oliva*, *Fasciolaria*, *Crassatella*, and others. The absence also of large cowries (*Cyprea*) is remarkable, those found belonging exclusively to the section *Trivia.* The large volute, called *Voluta Lamberti* (fig. 126, p. 177), may seem an exception ; but it differs in form from the volutes of the torrid zone, and its nearest living ally, *Voluta Junonia*, has been dredged up (as before stated p. 177) in the Gulf-stream in extra-tropical latitudes.

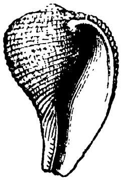
The occurrence of a species of *Lingula* at Sutton (see fig. 132) is worthy of remark, as this genus of *Brachiopoda* is now confined to more equatorial latitudes ; and the same may be said still more decidedly of a species of *Pyrula*, supposed by Mr. Wood to be identical with *P. reticulata* (fig. 133), now living in the Indian Ocean. A genus also of echinoderms, called by Professor Forbes *Temnechinus* (fig. 134), occurs in the Red and Coralline Crag of Suffolk, and until lately was unknown in a living state, but it has been brought to light as an existing form by the deep-sea dredgings, both of the United States survey, off Florida, at a depth of from 180 to 480 feet, and more recently (1869) in the British seas, during the explorations of the 'Porcupine.'

Fig. 132.



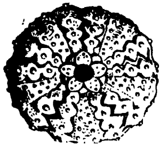
Lingula Dumortieri, Nyst ; Suffolk and Antwerp Crag.

Fig. 133.



Pyrula reticulata, Lam. ; Coralline Crag, Ramsholt.

Fig. 134.



Temnechinus excavatus, Forbes ; *Temnopleurus excavatus*, Wood ; Cor. Crag, Ramsholt.

Climate of the Crag Deposits.—One of the most interesting conclusions deduced from a careful comparison of the shells of the British Pliocene strata and the fauna of our present seas has been pointed out by Professor E. Forbes. It appears that, during the Glacial period, an epoch intermediate, as we have seen, between that of the Crag and our own time, many shells, previously established in the temperate zone, retreated southwards to avoid an uncongenial climate, and they have been found fossil in the Newer Pliocene strata of Sicily, Southern

Italy, and the Grecian Archipelago, where they may have experienced, during the era of floating icebergs, a climate resembling that now prevailing in higher European latitudes.[1] The Professor gave a list of fifty shells which inhabited the British seas while the Coralline and Red Crag were forming, and which, though now living in our seas, were wanting, as far as was then known, in the glacial deposits. Some few of these species have subsequently been found in the glacial drift, but the general conclusion of Forbes remains unshaken. This view is ably supported by Mr. Searles Wood in the concluding remarks of his Supplement to the Crag Mollusca,[2] where he points out how the geographical changes produced by that sinking down of land which accompanied the Glacial period may have altered the coast line, shutting out a former connection with the Mediterranean, and opening for a time a new one with the Scandinavian seas.[3]

The transport of blocks by ice, when the Red Crag was being deposited, appears to me evident from the huge size of some irregular, quite unrounded chalk flints, retaining their white coating, and 2 feet long by 18 inches broad, in beds worked for phosphatic nodules at Foxhall, four miles south-east of Ipswich. These must have been tranquilly drifted to the spot by floating ice. Mr. Prestwich also mentions the occurrence of a large block of porphyry at the base of the Coralline Crag at Sutton, which would imply that the ice-action had begun in our seas even in this older period. The cold seems to have gone on increasing from the time of the Coralline to that of the Norwich Crag, and became more and more severe, not perhaps without some oscillations of temperature, until it reached its maximum in what has been called the Glacial period, or at the close of the Newer Pliocene, and in the Pleistocene periods.

Relation of the Fauna of the Crag to that of the recent Seas.—By far the greater number of the marine species occurring in the several Crag formations are still inhabitants of the British seas; but even these differ considerably in their relative abundance, some of the commonest of the Crag shells being now extremely scarce—as, for example, *Buccinum Dalei*—while others, rarely met with in a fossil state, are now very common, as *Murex erinaceus* and *Cardium echinatum*. Some of the species also, the identity of which with the living would not be disputed by any conchologist, are nevertheless distinguishable as varieties, whether by slight deviations in form or a difference in average dimensions. Since Mr. Searles Wood first described the marine testacea of the Crags, the additions made to that fossil fauna have been considerable, but those made in the same period to our knowledge of the living testacea of the British and arctic seas and of the Mediterranean have been much greater. By this means the naturalist has been enabled to identify with existing species many forms previously supposed to be extinct. The recent careful deep-sea dredgings of Mr. Gwyn Jeffreys and his companions have led to the discovery of some few Mediterranean species of shells as still living in the abysmal depths of the ocean, which were formerly regarded as extinct members of the Coralline Crag fauna. But in spite of this resuscitation, as it might be called, of a few fossil forms, Mr. Searles Wood finds that they scarcely produce any appreciable difference in the percentage given by him of forms unknown as living. Such generalisations must however always depend on the limits assigned different naturalists to the terms 'species' and 'variety.'

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[1] E. Forbes, Mem. Geol. Survey Gt. Brit., vol. i. p. 386.

[2] Paleontographical Society, 1873.

[3] For a fuller discussion of the climate of the Crags see Antiquity of Man, 4th ed. 1873, pp. 248–253.

NUMBER OF KNOWN SPECIES OF MARINE TESTACEA IN THE CRAG.

CHILLESFORD AND ALDEBY BEDS.

	Total Number	Not Known as Living	Percentage of Shells not Known as Living
Bivalves	51	7	15·9
Univalves	36	7	
Brachiopods	1	0	

NORWICH OR FLUVIO-MARINE CRAG.

Bivalves	52	7	16·0
Univalves	59	11	
Brachiopods	1	0	

RED CRAG.

(*Exclusive of many derivative shells.*)

Bivalves	112	28	27·8
Univalves	134	40	
Brachiopods	2	1	

CORALLINE CRAG.

Bivalves	169	60	36·0
Univalves	222	82	
Brachiopods	5	2	

In the supplement to the invaluable monograph above alluded to, Mr. Wood has completed his figures and descriptions of the British Crag shells of every age, and lists are given of all the fossil shells, of which a summary will be found in the preceding table.

To begin with the uppermost or Chillesford beds, it will be seen that about 15 per cent. are extinct, or not known as living; while in the Norwich, which succeeds in the descending order, 16 in 100 are extinct. Formerly, when the Norwich or Fluvio-marine Crag was spoken of, both these formations were included under the same head, for both at Bramerton and Thorpe, the chief localities where the Norwich Crag was studied, an overlying deposit occurs referable to the Chillesford age.

To come next to the Red Crag, the reader will observe that a percentage of 27 is given of shells unknown as living, and this increases to 36 in the antecedent Coralline Crag. But the gap between these two stages of our Pliocene deposits is really wider than these numbers would indicate, for several reasons. In the first place, the Coralline Crag is more strictly the product of a single period; the Red Crag, as we have seen, consisting of separate and independent patches, slightly varying in age, of which the newest, or that called by Mr. Searles Wood the Scrobularia Crag, is probably not much anterior to the Norwich Crag. Indeed the connection between this newest portion of the Red Crag and the overlying Norwich Crag is so much closer than any which exists between the oldest and newest portions of the Red Crag itself, that Mr. Searles Wood inclines to the opinion that these two upper divisions of the Crag 'with their overlying Chillesford clay and sand can be regarded only as one deposit constituting in England the upper Crag, as the Coralline does the lower; and that the triple division of the Crag which has for so many years been assumed must be abandoned.' On the other hand, between the periods of the Coralline and Red Crag, there was a great change of conditions, both as to the depth of the sea and climate, causing the fauna in each to differ far more widely than would appear from the above numerical results.

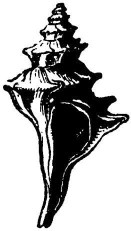
The value of the analysis given in the above table of the shells of the Red and Coralline Crags is in no small degree enhanced by the fact that they were all either collected by Mr. Wood himself, or obtained by him direct from their discoverers, so that he was enabled in each case to test their authenticity, and as far as possible to avoid those errors which arise from confounding together shells belonging to the sea of a newer deposit and those washed into it from a formation of older date. The danger of this confusion may be conceived when we remember that the number of species rejected from the Red Crag as derivative by Mr. Wood is no less than 87. Some geologists have held that on the same grounds it is necessary to exclude as derivative some of the species found in the Norwich Crag proper ; but Mr. Wood does not entertain this view, believing that the spurious shells which have sometimes found their way into the lists of this Crag have been introduced through want of care from Red Crag strata.

There can be no doubt, on the other hand, that conchologists have occasionally rejected from the Red and Norwich Crags, as derivative, shells which really belonged to the seas of those periods, because they were extinct or unknown as living, which in their eyes afforded sufficient ground for suspecting them to be intruders. The derivative origin of a species may sometimes be indicated by the extreme scarcity of the individuals, their colour, and worn condition ; whereas an opposite conclusion may be arrived at by the integrity of the shells, especially when they are of delicate and tender structure, or their abundance, and, in the case of the lamellibranchiata, by their being held together by the ligament, which often happens when the shells have been so broken that little more than the hinges of the two valves are preserved. As to the univalves, I have seen from a Red Crag pit, near Woodbridge, a large individual of the extinct *Voluta Lamberti*, seven inches in length, of which the lip, then perfect, had in former stages of its growth been frequently broken, and as often repaired. It had evidently lived in the sea of the Red Crag, where it had been exposed to rough usage, and sustained injuries like those which the reversed whelk, *Trophon antiquum*, so characteristic of the same formation, often exhibits. Additional proofs, however, have lately been obtained by Mr. Searles Wood that *Voluta Lamberti* had not died out in the era of the Red Crag, by the discovery of the same fossil, near Southwold, in beds of the later Norwich Crag.

Antwerp Crag.—Strata of the same age as the Red and Coralline Crag of Suffolk have been long known in the country round Antwerp, and on the banks of the Scheldt, below that city ; and the lowest division, or Black Crag, there found, is shown by the shells to be somewhat more ancient than any of our British series, and probably forms the first links of a downward passage from the strata of the Pliocene to those of the Upper Miocene period.

Newer Pliocene Strata of Sicily.—At several points north of Catania, on the eastern sea-coast of Sicily—as at Aci-Castello, for example, Trezza, and Nizzeti—marine strata, associated with volcanic tuffs and basaltic lavas, are seen, which belong to a period when the first igneous eruptions of Mount Etna were taking place in a shallow bay of the Mediterranean. They contain numerous fossil shells, and out of 142 species that have been collected all but eleven are identical with species now living. Some few of these eleven shells may possibly still linger in the depths of the Mediterranean, like *Murex vaginatus*, see fig. 135. The last-mentioned shell had already become rare when the associated marine and volcanic strata above alluded to were formed. On the whole, the modern character of the testaceous fauna under consideration is expressed not only by the small proportion of extinct species, but by the relative number of individuals by which most of the other species are represented, for the proportion agrees with that observed in the present fauna of the Mediterranean. The rarity of individuals in the extinct species is such as to imply that they were already on the point of dying out, having flourished chiefly in the earlier Pliocene times, when the Subapennine strata were in progress.

Fig. 135.



Murex vaginatus, Phil.

Yet since the accumulation of these Newer Pliocene sands and clays, the whole cone of Etna, 11,000 feet in height and about 90 miles in circumference at its base, has been slowly built up; an operation requiring many thousands of years for its accomplishment, and to estimate the magnitude of which it is necessary to study in detail the internal structure of the mountain, and to see the proofs of its double axis, or the evidence of the lavas of the present great centre of eruption having gradually overwhelmed and enveloped a more ancient cone, situated 3½ miles to the east of the present one.[1]

It appears that while Etna was increasing in bulk by a series of eruptions, its whole mass, comprising the foundations of subaqueous origin above alluded to, was undergoing a slow upheaval by which those marine strata were raised to the height of 1,200 feet above the sea, as seen at Catera, and perhaps to greater heights, for we cannot trace their extension westward, owing to the dense and continuous covering of modern lava under which they are buried. During the gradual rise of these Newer Pliocene formations (consisting of clays, sands, and basalts), other strata of Pleistocene date, marine as well as fluviatile, accumulated round the base of the mountain, and these, in their turn, partook of the upward movement, so that several inland cliffs and terraces at low levels, due partly to the action of the sea and partly to the river Simeto, originated in succession. Fossil remains of the elephant, and other extinct quadrupeds, have been found in these Pleistocene strata, associated with recent shells.

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[1] See a Memoir on the Lavas and Mode of Origin of Mount Etna, by the Author, Phil. Trans. 1858.

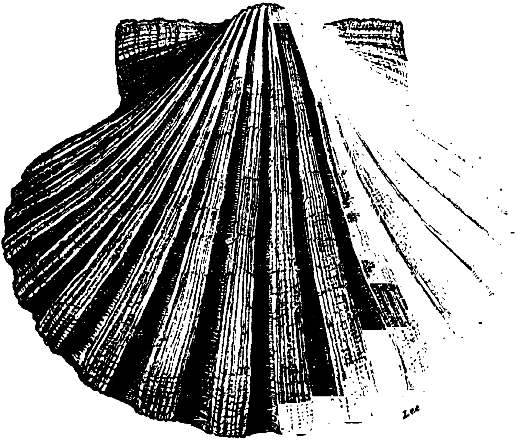
There is probably no part of Europe where the Newer Pliocene formations enter so largely into the structure of the earth's crust, or rise to such heights above the level of the sea, as Sicily. They cover nearly half the island, and near its centre, at Castrogiovanni, reach an elevation of 3,000 feet. They consist principally of two divisions, the upper calcareous, and the lower argillaceous, both of which may be seen at Syracuse, Girgenti, and Castrogiovanni. According to Philippi, to whom we are indebted for the best account of the tertiary shells of this island, 35 species out of 124 obtained from the beds in central Sicily are extinct.

A geologist, accustomed to see nearly all the Newer Pliocene formations in the north of Europe occupying low grounds and very incoherent in texture, is naturally surprised to behold formations of the same age so solid and stony, of such thickness, and attaining so great an elevation above the level of the sea. The upper or calcareous member of this group in Sicily consists in some places of a yellowish-white stone, like the Calcaire Grossier of Paris; in others, of a rock nearly as compact as marble. Its aggregate thickness amounts sometimes to 700 or 800 feet. It usually occurs in regular horizontal beds, and is occasionally intersected by deep valleys, such as those of Sortino and Pentalica, in which are numerous caverns. The fossils are in every stage of preservation, from shells retaining portions of their animal matter and colour to others which are mere casts. The limestone passes downwards into a sandstone and conglomerate, below which is clay and blue marl, from which perfect shells and corals may be disengaged. The clay sometimes alternates with yellow sand.

South of the plain of Catania is a region in which the tertiary beds are intermixed with volcanic matter, which has been for the most part the product of submarine eruptions. It appears that, while the clay, sand, and yellow limestone before mentioned were in course of deposition at the bottom of the sea, volcanoes burst out beneath the waters, like that of Graham Island, in 1831, and these explosions recurred again and again at distant intervals of time. Volcanic ashes and sand were showered down and spread by the waves and currents so as to form strata of tuff, which are found intercalated between beds of limestone and clay containing marine shells, the thickness of the whole mass exceeding 2,000 feet. The fissures through which the lava rose may be seen in many places forming what are called *dikes*.

No shell is more conspicuous in these Sicilian strata than the great scallop, *Pecten jacobæus* (fig. 136), now so common in the neighbouring seas. The more we reflect on the preponderating number of this and other recent shells, the more we are surprised at the great thickness, solidity, and height above the sea of the rocky masses in which they are entombed, and the vast amount of geographical change which has taken place since their origin. It must be remembered that, before they began to emerge, the uppermost strata of the whole must have been deposited under water. In order, therefore, to form a just conception of their antiquity, we must first examine singly the innumerable minute parts of which the whole is made up, the successive beds of shells, corals, volcanic ashes, conglomerates, and sheets of lava; and we must afterwards contemplate the time required for the gradual upheaval of the rocks, and the excavation of the valleys. The historical period seems scarcely to form an appreciable unit in this computation, for we find ancient Greek temples, like those of Girgenti (Agrigentum), built of the modern limestone of which we are speaking, and resting on a hill composed of the same; the site having remained to all appearances unaltered since the Greeks first colonised the island.

Fig. 136.



Pecten jacobæus; half natural size.

It follows, from the modern geological date of these rocks, that the fauna and flora of a large part of Sicily are of higher antiquity than the country itself. The greater part of the island has been raised above the sea since the epoch of existing species, and the animals and plants now inhabiting it must have migrated from adjacent countries, with whose productions the species are now identical. The average duration of species would seem to be so great, that they are destined to outlive many important changes in the configuration of the earth's surface, and hence the necessity for those innumerable contrivances by which they are enabled to extend their range to new lands as they are formed, and to escape from those which sink beneath the sea.

Newer Pliocene strata of the Upper Val d'Arno.—When we ascend the Arno for about 10 miles above Florence, we arrive at a deep narrow valley, called the Upper Val d'Arno, which appears once to have been a lake, at a time when the valley below Florence was an arm of the sea. The horizontal lacustrine strata of this upper basin are 12 miles long and 2 broad. The depression which they fill has been excavated out of Eocene and Cretaceous rocks, which form everywhere the sides of the valley in highly inclined stratification. The thickness of the more modern and unconformable beds is about 750 feet, of which the upper 200 feet consist of Newer Pliocene strata, while the lower are older Pliocene. The newer series are made up of sands and a conglomerate called 'sansino.' Among the imbedded fossil mammalia are *Mastodon arvernensis*, *Elephas meridionalis*, *Rhinoceros etruscus*, *Hippopotamus major*, and remains of the genera bear, hyæna, and felis, nearly all of which occur in the Cromer forest-bed (see p. 172).

In the same upper strata are found, according to M. Gaudin, the leaves and cones of *Glyptostrobus europæus*, a plant closely allied to *G. heterophyllus*, now inhabiting the north of China and Japan. This conifer had a wide range in time, having been traced back to the Lower Miocene strata of Switzerland—and being common at Œningen in the Upper Miocene, as we shall see in the sequel (p. 205).

Older Pliocene of Italy.—Subapennine strata.—The Apennines, it is well known, are composed chiefly of Secondary or Mesozoic rocks, forming a chain which branches off from the Ligurian Alps and passes down the middle of the Italian peninsula. At the foot of these mountains, on the side both of the Adriatic and the Mediterranean, are found a series of tertiary strata, which form, for the most part, a line of low hills occupying the space between the older chain and the sea. Brocchi was the first Italian geologist who described this newer group in detail, giving it the name of the Subapennine. Though chiefly composed of Older Pliocene strata, it belongs nevertheless, in part, both to older and newer members of the tertiary series. The strata, for example, of the Superga, near Turin, are Miocene; those of Asti and Parma Older Pliocene, as is the blue marl of Sienna; while the shells of the incumbent yellow sand of the same territory approach more nearly to the recent fauna of the Mediterranean, and may be Newer Pliocene.

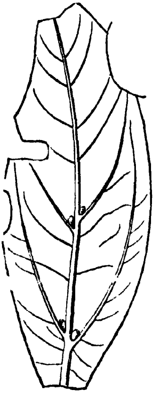
We have seen that most of the fossil shells of the Older Pliocene strata of Suffolk which are of recent species are identical with testacea now living in British seas, yet some of them belong to Mediterranean species, and a few even of the genera are those of warmer climates. We might therefore expect, in studying the fossils of corresponding age in countries bordering the Mediterranean, to find among them some species and genera of warmer latitudes. Accordingly, in the marls belonging to this period at Asti, Parma, Sienna, and parts of the Tuscan and Roman territories, we observe the genera *Conus*, *Cypræa*, *Strombus*, *Pyrula*, *Mitra*, *Fasciolaria*, *Sigaretus*, *Delphinula*, *Ancillaria*, *Oliva*, *Terebellum*, *Terebra*, *Perna*, *Plicatula*, and *Corbis*, some characteristic of tropical seas, others represented by species more numerous or of larger size than those now proper to the Mediterranean.

Older Pliocene flora of Italy.—I have already alluded to the Newer Pliocene deposits of the Upper Val d'Arno above Florence, and stated that below those sands and conglomerates, containing the remains of the *Elephas meridionalis* and other associated quadrupeds, lie an older horizontal and conformable series of beds, which may be classed as Older Pliocene. They consist of blue clays with some subordinate layers of lignite, and exhibit a richer flora than the overlying Newer Pliocene beds, and one receding farther from the existing vegetation of Europe. They also comprise more species common to the antecedent Miocene period. Among the genera of flowering plants, M. Gaudin enumerates pine, oak, evergreen oak, plum, plane, alder, elm, fig, laurel, maple, walnut, birch, buckthorn, hiccory, sumach, sarsaparilla, sassafras, cinnamon, Glyptostrobus, Taxodium, Sequoia, Persea, Oreodaphne (fig. 137), Cassia, Psoralea, and some others. This assemblage of plants indicates a warm climate, but not so subtropical an one as that of the Upper Miocene period, which will presently be considered.

M. Gaudin, jointly with the Marquis Strozzi, has thrown much light on the botany of beds of the same age in another part of Tuscany, at a place called Montajone, between the rivers

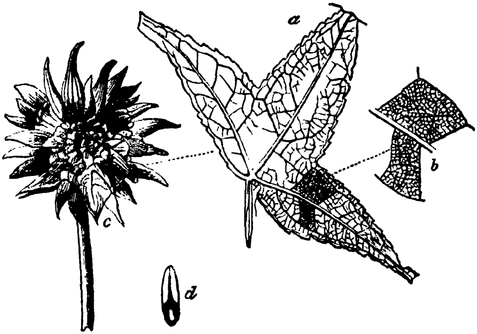
Elsa and Evola, where, among other plants, is found the *Oreodaphne Heerii*, Gaud. (see fig. 137), which is probably only a variety of *Oreodaphne fœtens*, or the laurel called the Til in Madeira, where, as in the Canaries, it constitutes a large portion of the native woods, but cannot now endure the climate of Europe. In the fossil specimens the same glands or protuberances are preserved[2] (see fig. 137), as those which are seen in the axils of the primary veins of the leaves in the recent Til. Another plant also indicating a warmer climate is the *Liquidambar europæum*, Brong. (see fig. 138), a species nearly allied to *L. styraciflum*, L., which flourishes in most places in the Southern States of North America, on the borders of the Gulf of Mexico.

Fig. 137.



Oreodaphne Heerii. Leaf half nat. size.[1]

Fig. 138.



Liquidambar europæum, var. *trilobatum*, A. Br.; (sometimes 4 lobed and more commonly 5 lobed).
a. Leaf, half nat. size. *c.* Fruit, nat. size.
b. Part of same, nat. size. *d.* Seed, do. Œningen.

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[1] Feuilles fossiles de la Toscane.

[2] Contributions à la Flore fossile italienne. Gaudin and Strozzi. Plate 11, fig. 3. Gaudin, p. 22.

CHAPTER XIV.

MIOCENE PERIOD—UPPER MIOCENE.

Upper Miocene strata of France—Faluns of Touraine—Tropical climate implied by testacea—Proportion of recent species of shells—Faluns more ancient than the Suffolk Crag—Upper Miocene of Bordeaux and the south of France—Upper Miocene of Œningen in Switzerland—Plants of the Upper freshwater Molasse—Fossil fruit and flowers as well as leaves—Insects of the Upper Molasse—Middle or Marine Molasse of Switzerland—Upper Miocene beds of the Bolderberg in Belgium—Vienna basin—Upper Miocene of Italy and Greece—Upper Miocene of India; Siwâlik hills—Older Pliocene and Miocene of the United States.

Upper Miocene strata of France.—Faluns of Touraine.—The strata which we meet with next in the descending order are those called by many geologists 'Middle Tertiary,' for which in 1833 I proposed the name of Miocene, selecting the 'faluns' of the valley of the Loire in France as my example or type. I shall now call these falunian deposits Upper Miocene,[1] to distinguish them from others to which the name of Lower Miocene will be given.

No British strata have a distinct claim to be regarded as Upper Miocene; and as the Lower Miocene are also but feebly represented in the British Isles, we must refer to foreign examples in illustration of this important period in the earth's history. The term 'faluns' is given provincially by French agriculturists to shelly sand and marl spread over the land in Touraine, just as similar shelly deposits were formerly much used in Suffolk to fertilise the soil, before the coprolitic or phosphatic nodules came into use. Isolated masses of such faluns occur from near the mouth of the Loire, in the neighbourhood of Nantes, to as far inland as a district south of Tours. They are also found at Pontlevoy, on the Cher, about seventy miles above the junction of that river with the Loire, and thirty miles S.E. of Tours. Deposits of the same age also appear under new mineral conditions near the towns of Dinan and Rennes, in Brittany. I have visited all the localities above enumerated, and found the beds on the Loire to consist principally of sand and marl, in which are shells and corals, some entire, some rolled, and others in minute fragments. In certain districts, as at Doué, in the Department of Maine and Loire, ten miles S.W. of Saumur, they form a soft building-stone, chiefly composed of an aggregate of broken shells, polyzoa, corals, and echinoderms, united by a calcareous cement; the whole mass being lithologically very like the Coralline Crag near Aldborough and Sudbourn in Suffolk. The scattered patches of faluns are of slight thickness, rarely exceeding fifty feet; and between the district called La Sologne and the sea they repose on a great variety of older rocks; being seen to rest successively upon gneiss, clay-slate, various secondary formations, including the chalk; and, lastly, upon the upper fresh-water limestone of the Parisian tertiary series, which, as before mentioned (p. 119), stretches continuously from the basin of the Seine to that of the Loire.

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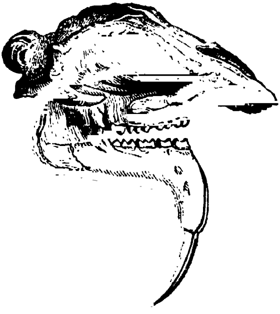
[1] In the recent works of M. Gaudry and M. Milne-Edwards the Upper Miocene is subdivided into Upper and Middle; but it would seem that the two authors do not entirely agree, M. Gaudry placing Eppelsheim in the Upper, and Milne-Edwards in the Middle Miocene.

At some points, as at Louans, south of Tours, the shells are stained of a ferruginous colour, not unlike that of the Red Crag of Suffolk. The species are, for the most part, marine, but a few of them belong to land and fluviatile genera. Among the former, *Helix turonensis* (fig. 38, p. 32) is the most abundant. Remains of terrestrial quadrupeds are here and there intermixed, belonging to the genera Dinotherium (fig. 139), Mastodon, Rhinoceros, Hippopotamus, Chæropotamus, Dichobune, Deer, and others, and these are accompanied by cetacea, such as the Lamantine, Morse, Sea-Calf, and Dolphin, all of extinct species.

Fig. 139.



Dinotherium giganteum, Kaup.

The fossil testacea of the faluns of the Loire imply, according to the late Edward Forbes, that the beds were formed partly on the shore itself at the level of low water, and partly at very moderate depths, not exceeding ten fathoms below that level. The molluscan fauna is on the whole much more littoral than that of the Pliocene Red and Coralline Crag of Suffolk, and implies a shallower sea. It is, moreover, contrasted with the Suffolk Crag by the indications it affords of an extra-European climate. Thus it contains seven species of *Cypræa*, some larger than any existing cowry of the Mediterranean, several species of *Oliva*, *Ancillaria*, *Mitra*, *Terebra*, *Pyrula*, *Fasciolaria*, and *Conus*. Of the cones there are no less than eight species, some very large, whereas the only European cone now living is of diminutive size. The genus *Nerita*, and many others, are also represented by individuals of a type now characteristic of equatorial seas, and wholly unlike any Mediterranean forms. These proofs of a more elevated temperature seem to imply the higher antiquity of the faluns as compared with the Suffolk Crag, and are in perfect accordance with the fact of the smaller proportion of testacea of recent species found in the faluns.

Out of 290 species of shells, collected by myself in 1840 at Pontlevoy, Louans, Bossée, and other villages twenty miles south of Tours, and at Savigné, about fifteen miles north-west of that place, seventy-two only could be identified with recent species, which is in the proportion of twenty-five per cent. A large number of the 290 species are common to all the localities, those peculiar to each not being more numerous than we might expect to find in different bays of the same sea.

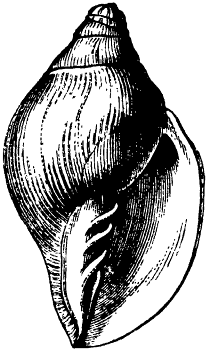
The total number of species of testaceous mollusca from the faluns in my possession is 302, of which 45 only, or fourteen per cent., were found by Mr. Wood to be common to the Suffolk Crag. The number of polyzoa and zoantharia obtained by me at Doué, and other localities before adverted to, amounts to 43 as determined by Mr. Lonsdale, of which seven (one of them a zoantharian) agree specifically with those of the Suffolk Crag. Some of the genera occurring fossil in Touraine, as the corals *Astrea* and *Dendrophyllia*, and the polyzoan *Lunulites*, have not been found in European seas north of the Mediterranean; nevertheless the zoantharia of the faluns do not seem to indicate on the whole so warm a climate as would have been inferred from the shells.

It was stated that, on comparing about 300 species of Touraine shells with about 450 from the Suffolk Crag, 45 only were found to be common to both, which is in the proportion of only fifteen per cent. The same small amount of agreement is found in the corals also. I formerly endeavoured to reconcile this marked difference in species with the supposed co-existence of the two faunas, by imagining them to have severally belonged to distinct zoological provinces or two seas, the one opening to the north, and the other to the south, with a barrier of land between them, like the Isthmus of Suez, now separating the Red Sea and the Mediterranean. But I now abandon that idea for several reasons; among others, because I succeeded in 1841 in tracing the Crag fauna southwards in Normandy to within seventy miles of the falunian type, near Dinan, yet found that both assemblages of fossils retained their distinctive characters, showing no signs of any blending of species or transition of climate.

The principal grounds, however, for referring the English Crag to the Older Pliocene and the French faluns to the Upper Miocene epochs, consist in the predominance of fossil shells in the British strata identifiable with species, not only still living, but which are now inhabitants of neighbouring seas, while the accompanying extinct species are of genera such as characterise Europe. In the faluns, on the contrary, the recent species are in a decided minority; and most of them are now inhabitants of the Mediterranean, the coast of Africa, and the Indian Ocean; in a word, less northern in character, and pointing to the prevalence of a warmer climate. They indicate a state of things receding farther from the present condition of Central Europe in physical geography and climate, and doubtless, therefore, receding farther from our era in time.

Among the conspicuous fossils common to the faluns of the Loire and the Suffolk Crag, is a variety of the *Voluta Lamberti*, a shell already alluded to (p. 177, fig. 126). The specimens of this shell which I have myself collected in Touraine, or have seen in museums, are thicker and heavier than British individuals of the same species, and shorter in proportion to their width, and have the folds on the columella less oblique, as represented in the annexed figure.

Fig. 140.



Voluta Lamberti, Sow. Variety characteristic of Faluns of Touraine. Miocene.

Upper Miocene strata of Bordeaux and South of France.—A great extent of country between the Pyrenees and the Gironde is overspread by tertiary deposits of various ages and chiefly of Miocene date. Some of these, near Bordeaux, coincide in age with the faluns of Touraine, already mentioned, but many of the species of shells are peculiar to the south. The succession of beds in the basin of the Gironde implies several oscillations of level by which the same wide area was alternately converted into sea and land and into brackish-water lagoons, and finally into freshwater ponds and lakes.

Among the freshwater strata of this age near the base of the Pyrenees are marls, limestones, and sands, in which the eminent comparative anatomist, M. Lartet, obtained a great number of fossil mammalia common to the faluns of the Loire and the Upper Miocene beds of Switzerland, such as *Dinotherium giganteum* and *Mastodon angustidens.* More lately M. Gaudry has enumerated 16 species of vertebrata from strata of this age at Mont Léberon in Vaucluse, among which are *Machærodus cultridens, Rhinoceros Schleiermacheri, Dinotherium giganteum,* and the gigantic ruminant *Helladotherium Duvernoyi* rivalling the giraffe in stature. This herbivore had a wide range over Europe and Asia, its remains having been found in Greece and India. But the most remarkable of all the remains found in the Upper Miocene strata of the south of France were the bones of quadrumana, or of the ape and monkey tribe, which were discovered by M. Lartet in 1837, the first of that order of quadrupeds detected in Europe. They occurred at Sansan, near Auch, in the Department of Gers, in latitude 43° 39′ N., about forty miles west of Toulouse. They were referred by MM. Lartet and Blainville to a genus closely allied to the Gibbon, to which they gave the name of *Pliopithecus.* When I visited Sansan in the spring of 1872 I came to the conclusion that the explanation of so many mammalia and other vertebrata being preserved at Sansan alone, in so very limited an area, was probably the partial recurrence of a very thick impervious marly deposit or layer in which the quadrupeds may have been bogged, and which prevented free percolation of water, whereas in general impervious beds must have been wanting, so that all organic remains of the date of the faluns were destroyed where they happened to be imbedded.

In 1856, M. Lartet described another species of the same family of long-armed apes (*Hylobates*), which he obtained from strata of the same age at Saint-Gaudens in the Haute Garonne. The fossil remains of this animal consisted of a portion of a lower jaw with teeth and the shaft of a humerus. It is supposed to have been a tree-climbing frugivorous ape, equalling Man in stature. As the trunks of oaks are common in the lignite beds in which it lay, it has received the generic name of *Dryopithecus.* The angle formed by the ascending ramus of the jaw and the alveolar border is less open, and therefore more like the human subject, than in the Chimpanzee; and, what is still more remarkable, the fossil, a young but adult individual, had all its milk teeth replaced by the second set, while its last true molar (or wisdom tooth) was still undeveloped, or only existed as a germ in the jaw-bone. In the mode, therefore, of the succession of its teeth (which, as in all the Old-World apes, exactly agree in number with those in Man) it differed from the Gorilla and Chimpanzee, and corresponded with the human species.

Upper Miocene beds of Œningen in Switzerland.—The faluns of the Loire first served, as already stated (p. 192), as the type of the Miocene formations in Europe. They yielded a plentiful harvest of marine fossil shells and corals, but were entirely barren of plants and insects. In Switzerland, on the other hand, deposits of the same age have been discovered, remarkable for their botanical and entomological treasures. We are indebted to Professor Heer of Zurich for the description, restoration, and classification of several hundred species and varieties of these fossil plants, the whole of which he has illustrated by excellent figures in his 'Flora Tertiaria Helvetiæ.' This great work, and those of Adolphe Brongniart, Unger, Goeppert, and others, show that this class of fossils is beginning to play the same important part in the classification of the tertiary strata containing lignite or brown coal as an older flora has long played in enabling us to understand the ancient coal or carboniferous formation. No small scepticism has always prevailed among botanists as to whether the leaves alone and the wood of plants could ever afford sufficient data for determining even genera and families in the vegetable kingdom. In truth, before such remains could be rendered available, a new science had to be created. It was necessary to study the outlines, nervation, and microscopic structure of the leaves, with a degree of care which had never been called for in the classification of living plants, where the flower and fruit afforded characters so much more definite and satisfactory. As geologists, we cannot be too grateful to those who, instead of despairing when so difficult a task was presented to them, or being discouraged when men of the highest scientific attainments treated the fossil leaves as worthless, entered with full faith and enthusiasm into this new and unexplored field. That they should frequently have fallen into errors was unavoidable ; but it is remarkable, especially if we enquire into the history of Professor Heer's researches, how often early conjectures as to the genus and family founded on the leaves alone were afterwards confirmed when fuller information was obtained. As examples to be found on comparing Heer's earlier and later works, I may instance the chestnut, elm, maple, cinnamon, magnolia, buckbean or Menyanthes, vine, buckthorn (*Rhamnus*), *Andromeda*, and *Myrica*, and among the conifers *Sequoia* and *Taxodium*. In all these cases the plants were first recognised by their leaves ; and the accuracy of the determination was afterwards confirmed when the fruit, and in some instances both fruit and flower, were found attached to the same stem as the leaves.

But let us suppose that no fruit, seed, or flower had ever been met with in a fossil state, we should still have been indebted to the persevering labours of botanical palæontologists for one of the grandest scientific discoveries for which the present century is remarkable—namely, the proofs now established of the prevalence of a mild climate and a rich arborescent flora in the arctic regions in that Miocene epoch on the history of which we are now entering. It may be useful if I endeavour to give the reader in a few words some idea of the nature of the evidence of these important conclusions, to show how far they may be safely based on fossil leaves alone. When we begin by studying the fossils of the Newer Pliocene deposits, such as those of the Upper Val d'Arno, before alluded to, we perceive that the fossil foliage agrees almost entirely with the trees and shrubs of a modern European forest. In the plants of the Older Pliocene strata of the same region we observe a larger proportion of species and genera which, although they may agree with well-known Asiatic or other foreign types, are at present wanting in Italy. If we then examine the Miocene formations of the same country, exotic forms become more abundant, especially the palms, whether they belong to the European or American fan-palms, *Chamærops* and *Sabal* (fig. 154, p. 220), or to the more tropical family of the date-palms or *Phœnicites*, which last are conspicuous in the Lower Miocene beds of Central Europe. Although we have not found the fruit or flower of these palms in a fossil state, the leaves are so characteristic that no one doubts the family to which they belong, or hesitates to accept them as indications of a warm and sub-tropical climate.

When the Miocene formations are traced to the northward of the 50th degree of latitude, the fossil palms fail us; but the greater proportion of the leaves, whether identical with those of existing European trees or of forms now unknown in Europe, which had accompanied the Miocene palms, still continue to characterise rocks of the same age, until we meet with them not only in Iceland, but in Greenland, in latitude 70° N., and in Spitzbergen, lat. 78° 56′, or within about 11 degrees of the pole, and under circumstances which clearly show them to have been indigenous in those regions, and not to have been drifted from the south (see p. 222). Not only, therefore, has the botanist afforded the geologist much palæontological assistance in identifying distinct tertiary formations in distant places by his power of accurately discriminating the forms, veining, and microscopic structure of leaves or wood, but independently of that exact knowledge, derivable from the organs of fructification, we are indebted to him for one of the most novel and unexpected results of modern scientific enquiry.

The Miocene formations of Switzerland have been called

Molasse, a term derived from the French *mol*, and applied to a *soft*, incoherent, greenish sandstone, occupying the country between the Alps and the Jura. This molasse comprises three divisions, of which the middle one is marine, and, being closely related by its shells to the faluns of Touraine, may be classed as Upper Miocene. The two others are freshwater, the upper of which may be also grouped with the faluns, while the lower must be referred to the Lower Miocene, as defined in the next chapter.

Upper freshwater Molasse.—This formation is best seen at Œningen, in the valley of the Rhine, between Constance and Schaffhausen, a locality celebrated for having produced in the year 1700 the supposed human skeleton called by Scheuchzer 'homo diluvii testis,' a fossil afterwards demonstrated by Cuvier to be a reptile, or aquatic salamander, of larger dimensions than even its great living representative the salamander of Japan.

The Œningen strata consist of a series of marls and limestones, many of them thinly laminated, and which appear to have slowly accumulated in a lake probably fed by springs holding carbonate of lime in solution. The elliptical area over which this freshwater formation has been traced extends, according to Sir Roderick Murchison, for a distance of ten miles east and west from Berlingen, on the right bank of the river to Wangen, and to Œningen, near Stein, on the left bank. The organic remains have been chiefly derived from two quarries, the lower of which is about 550 feet above the level of the Lake of Constance, while the upper quarry is 150 feet higher. In this last, a section thirty feet deep displays a great succession of beds, most of them splitting into slabs, and some into very thin laminæ. Twenty-one beds are enumerated by Professor Heer, the uppermost a bluish-grey marl seven feet thick, with organic remains, resting on a limestone with fossil plants, including leaves of poplar, cinnamon, and pond-weed (*Potamogeton*), together with some insects; while in the bed No. 4, below, is a bituminous rock, in which the *Mastodon tapiroides*, a characteristic Upper Miocene quadruped, has been met with. The 5th bed, two or three inches thick, contains fossil fish, e.g. *Leuciscus* (roach), and the larvæ of dragon-flies, with plants such as the elm (*Ulmus*), and the aquatic Chara. Below this are other plant-beds; and then, in No. 9, the stone in which the great salamander (*Andrias Scheuchzeri*) and some fish were found. Below this, other strata occur with fish, tortoises, the great salamander before alluded to, freshwater mussels, and plants. In No. 16 the fossil fox of Œningen, *Galecynus Œningensis*, Owen, was obtained by Sir R. Murchison. To this succeed other beds with mammalia (*Lagomys*), reptiles (*Emys*), fish, and plants, such as walnut, maple, and poplar. In the 19th bed are numerous fish, insects, and plants, below which are marls of a blue indigo colour.

In the lower quarry eleven beds are mentioned, in which, as in the upper, both land and freshwater plants and many insects occur. In the 6th, reckoning from the top, many plants have been obtained, such as *Liquidambar*, *Cinnamomum*, *Podogonium*, and *Ulmus*, together with tortoises, besides the bones and teeth of a ruminant quadruped, named by H. von Meyer *Paleomeryx eminens*. No. 9 is called the insect bed, a layer only a few inches thick, which, when exposed to the frost, splits into leaves as thin as paper. In these thin laminæ plants such as *Liquidambar*, *Cinnamomum*, and *Glyptostrobus* occur, with innumerable insects in a wonderful state of preservation, usually found singly. Below this is an indigo-blue marl, like that at the bottom of the higher quarry, resting on yellow marl ascertained to be at least thirty feet thick.

All the above fossil-bearing strata were evidently formed with extreme slowness. Although the fossiliferous beds are, in the aggregate, not more than a few yards in thickness, and have only been examined in the small area comprised in the two quarries just alluded to, they give us an insight into the state of animal and vegetable life in part of the Upper Miocene period, such as no other region in the world has elsewhere supplied. In the year 1859, Prof. Heer had already determined no less than 475 species of plants and more than 800 insects from these Œningen beds. He supposes that a river entering a lake floated into it some of the leaves and land insects, together with the carcases of quadrupeds, among others a great Mastodon. Occasionally, during tempests, twigs and even boughs of trees with their leaves were torn off and carried for some distance so as to reach the lake. Springs, containing carbonate of lime, seem at some points to have supplied calcareous matter in solution, giving origin locally to a kind of travertin, in which organic bodies sinking to the bottom became hermetically sealed up.

In his work entitled 'The Naturalist of the Amazons,' Mr. Bates mentions having observed on the Tapajos river in Brazil the dead or half-dead bodies of ants heaped up in a line an inch or two in height and breadth for miles along the beach.[1] I am also informed by the same naturalist that on the sandy shores of Lake Ega, on the Upper Amazons, he saw on several occasions sloping ridges of dead insects of all orders piled up on the margin of the lake. This sudden destruction of whole shoals of insects is caused, he says, by a sudden chill and squall occurring in the night over a wide expanse of water after a hot evening. The insects are tempted to fly by the sultry weather, the chill and storm overtake them, and they are cast into the water, the waves of which wash their bodies on to the lee-shore. Sand is also often thrown up at the same time, and some of the insects are thus buried a little above the water-line.

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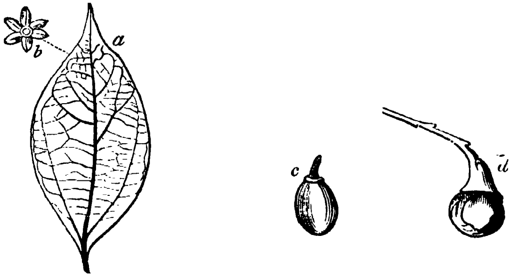
[1] Naturalist of the Amazons, 1863, vol. ii. p. 85.

The laminæ of the Œningen beds which immediately succeed each other were not all formed, according to Prof. Heer, at the same season, for it can be shown that, when some of them originated, certain plants were in flower, whereas, when the next of these layers was produced, the same plants had ripened their fruit. This inference is confirmed by independent proofs derived from insects. The principal insect-bed is rarely two inches thick, and is composed, says Heer, of about 250 leaf-like laminæ, some of which were deposited in the spring, when the *Cinnamomum polymorphum* (fig. 141) was in flower; others in summer, when winged ants were numerous, and when the poplar and willow had matured their seed; others, again, in autumn, when the same *Cinnamomum polymorphum* (fig. 141) was in fruit, as well as the liquidambar, oak, clematis, and many other plants. The ancient lake seems to have had a belt of poplars and willows round its borders, countless leaves of which were imbedded in mud, and together with them at some points a species of reed, *Arundo*, which was very common.

Fig. 141.



Cinnamomum polymorphum, Ad. Brong. Upper and Lower Miocene.

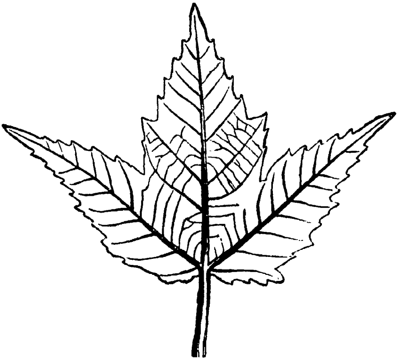
a. Leaf. *b.* Flower, nat. size. Heer, Pl. 93, fig. 28.
c. Ripe fruit of *Cinnamomum polymorphum*, from Œningen. Heer, Pl. 94, fig. 14.
d. Fruit of recent *Cinnamomum camphorum* of Japan. Heer, Pl. 152, fig. 18.

One of the most characteristic shrubs is a leguminous and papillionaceous plant of an extinct genus, called by Heer *Podo-*

gonium, of which two species are known. Entire twigs have been found with flowers, and always without leaves, as the flowers evidently came out, as in the poplar and willow tribe, before any leaves made their appearance. Other specimens have been obtained with ripe fruits accompanied by leaves, which resemble those of the tamarind, to which it was evidently allied, being of the family Cæsalpinæ, now proper to warmer regions.

The Upper Miocene flora of Œningen is peculiarly important, in consequence of the number of genera of which not merely the leaves, but, as in the case of the *Podogonium* just mentioned, the fruit also and even the flower are known. Thus there are nineteen species of maple, ten of which have already been found with fruit. Although in no one region of the globe do so many maples now flourish, we need not suspect Prof. Heer of having made too many species in this genus when we consider the manner in which he has dealt with one of them, *Acer trilobatum* (figs. 142, 143). Of this plant the number of marked varieties figured and named is very great, and no less than three of them had been considered as distinct species by other botanists, while six of the others might have laid claim, with nearly equal propriety, to a like distinction. The common form, called *Acer trilobatum*, fig. 142, may be taken as a normal representative of the Œningen fossil, and fig. 143 as one of the most divergent varieties, having almost four lobes in the leaf instead of three.

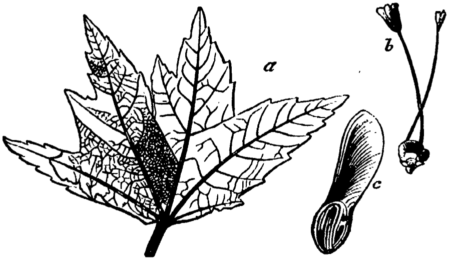
Fig. 142.



Acer trilobatum, normal form. Heer, Flora Tert. Helv., Pl. 114, fig. 2. Size ½ diam.
(Part only of the long stalk of the original fossil specimen is here given.)
Upper Miocene, Œningen; also found in Lower Miocene of Switzerland.

Among the conspicuous genera which abounded in the Miocene period in Europe is the plane-tree, *Platanus*, the fossil species being considered by Heer to come nearer to the American *P. occidentalis* than to *P. orientalis* of Greece and Asia Minor.

Fig. 143.



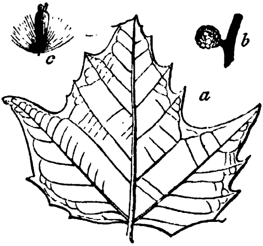
Acer trilobatum.

a. Abnormal variety of leaf. Heer, Pl. 110, fig. 16.
b. Flower and bracts, normal form. Heer, Pl. 111, fig. 21.
c. Half a seed-vessel. Heer, Pl. 111, fig. 5.

In some of the fossil specimens the male flowers are preserved. Among other points of resemblance with the living plane-trees, as we see them in the parks and squares of London, fossil fragments of the trunk are met with, having pieces of their bark peeling off.

The vine of Œningen, *Vitis teutonica*, Ad. Brong., is of a North American type. Both the leaves and seeds have been found at Œningen, and bunches of compressed grapes of the same species have been met with in the brown coal of Wetteravia in Germany. No less than eight species of smilax, a monocotyledonous genus, occur at Œningen and in other Upper Miocene localities, the flowers of some of them, as well as the leaves, being preserved, as in the case of the very common fossil, *Smilax sagittifera* (fig. 145, *a*).

Fig. 144.

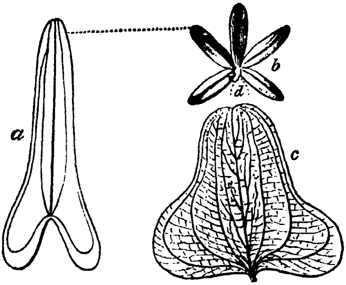


Platanus aceroides, Göpp.
Heer, Pl. 88, figs. 5–8.
Size ⅔ diam. Upper Miocene,
Œningen.
a. Leaf.
b. The core of a bundle of pericarps.
c. Single fruit or pericarp, nat. size.

Leaves of plants supposed to belong to the order Proteaceæ have been obtained partly from Œningen and partly from the lacustrine formation of the same age at Locle in the Jura.

They have been referred to the genera *Banksia*, *Grevillea*, *Hakea*, and *Persoonia*. Of Hakea there is the impression of a supposed seed-vessel, with its characteristic thick stalk and seeds; but as the fruit is without structure, and has not yet been found attached to the same stem as the leaf, the proof is incomplete.

Fig. 145.

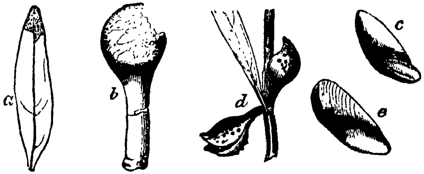


Smilax Sagittifera. Heer, Pl. 30, fig. 7. Size ½ diameter.

a. Leaf. *b.* Flower magnified, one of the six petals wanting at *d.* Upper Miocene, Œningen. *c. Smilax obtusifolia.* Heer, Pl. 30, fig. 9; nat. size. Upper Miocene, Œningen.

To whatever family the foliage hitherto regarded as proteaceous by many able palæontologists may eventually be shown to belong, we must be careful not to question their affinity to that order of plants on those geographical considerations which have influenced some botanists. The nearest living Proteaceæ now flourish in Abyssinia in lat. 20° N., but the greatest number are confined to the Cape and Australia. The ancestors, however, of the Œningen fossils ought not to be looked for in such distant regions, but from that European land which in Lower

Fig. 146.



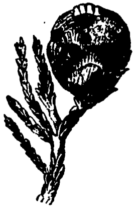
Fruit of the fossil and recent species of Hakea, a genus of Proteaceæ.

a. Leaf of fossil species, *Hakea salicina.* Upper Miocene, Œningen; Heer, Pl. 97, fig. 29. ⅓ diam. *b.* Impression of woody fruit of same, showing thick stalk. ⅔ diam. *c.* Seed of same; natural size. *d.* Fruit of living Australian species, *Hakea saligna*, R. Brown. ½ diam. *e.* seed of same; natural size.

Miocene times bore trees with similar foliage; and these had doubtless an Eocene source, for cones admitted by all botanists to be proteaceous have been met with in one division of that older Tertiary group (see fig. 209, p. 248). The source of these last, again, must not be sought in the antipodes, for in the cretaceous white sands and laminated clays of Aix-la-Chapelle leaves like those of Grevillea and other proteaceous genera have been found in abundance, and as we shall see (p. 287) in a most perfect state of preservation. All geologists agree that the distribution of the cretaceous land and sea had scarcely any connection with the present geography of the globe.

In the same beds with the supposed Proteaceæ there occurs at Locle a fan-palm of the American type Sabal (for genus see fig. 154), a genus which ranges throughout the low country near the sea from the Carolinas to Florida and Louisiana. Among the Coniferæ of Upper Miocene age is found a deciduous cypress nearly allied to the *Taxodium distichum* of North America, and a *Glyptostrobus* (fig. 147), very like the Japanese *G. heterophyllus*, now common in our shrubberies.

Fig. 147.



Glyptostrobus Europ
Branch with ripe fruit.
Heer, Pl. 20, fig. 1. Upper Miocene, Œningen.

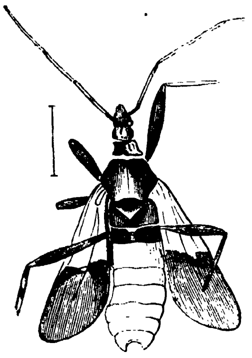
Before the appearance of Heer's work on the Miocene Flora of Switzerland, Unger and Göppert had already pointed out the large proportion of living North American genera which distinguished the vegetation of the Miocene period in Central Europe. Next in number, says Heer, to these American forms at Œningen the European genera preponderate, the Asiatic ranking in the third, the African in the fourth, and the Australian in the fifth degree. The American forms are more numerous than in the Italian Pliocene flora, and the whole vegetation indicates a warmer climate than the Pliocene, though not so high a temperature as that of the older or Lower Miocene period.

The conclusions drawn from the insects are for the most part in perfect harmony with those derived from the plants, but they have a somewhat less tropical and less American aspect, the South European types being more numerous. On the whole, the insect fauna is richer than that now inhabiting any part of Europe. No less than 844 species are reckoned by Heer from the Œningen beds alone, the number of specimens which he has examined being 5,080. The entire list of Swiss species from the Upper and Lower Miocene together amount to

1,322. Almost all the living families of Coleoptera are represented; but, as we might have anticipated from the preponderance of arborescent and ligneous plants, the wood-eating beetles play the most conspicuous part, the Buprestridæ and other long-horned beetles being particularly abundant.

The patterns and some remains of the colours both of *Coleoptera* and *Hemiptera* are preserved at Œningen; as, for example, in the annexed figure of *Harpactor*, in which the antennæ, one of the eyes, and legs and wings are retained. The characters, indeed, of many of the insects are so well defined as to incline us to believe that, if this class of the invertebrata were not so rare and local, they might be more useful than even the plants and shells in settling chronological points in geology.

Fig. 148.



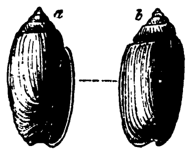
Harpactor maculipes, Heer. Upper Miocene, Œningen.

Middle or Marine Molasse (Upper Miocene) of Switzerland.—It was before stated that the Miocene formation of Switzerland consisted of, 1st, the upper freshwater molasse, comprising the lacustrine marls of Œningen; 2ndly, the marine molasse, corresponding in age to the faluns of Touraine; and 3rdly, the lower freshwater molasse. Some of the beds of the marine or middle series reach a height of 2,470 feet above the sea. A large number of the shells are common to the faluns of Touraine, the Vienna basin, and other Upper Miocene localities. The terrestrial plants play a subordinate part in the fossiliferous beds, yet more than ninety of them are enumerated by Heer as belonging to this falunian division, and of these more than half are common to subjacent Lower Miocene beds, while a proportion of about 45 in 100 are common to the overlying Œningen flora. 26 of the 92 species are peculiar.

Upper Miocene of the Bolderberg in Belgium.—In a small hill or ridge called the Bolderberg, which I visited in 1851, situated near Hasselt, about forty miles E.N.E. of Brussels, strata of sand and gravel occur, to which M. Dumont first called attention as appearing to constitute a northern representative of the faluns of Touraine. On the whole, they are very distinct in their fossils from the two upper divisions of the Antwerp Crag before mentioned (p. 185), and contain shells of the genera *Oliva*, *Conus*, *Ancillaria*, *Pleurotoma*, and *Cancellaria* in abundance. The most common shell is an Olive (fig. 149), called by Nyst *Oliva Dufresnii*; and constituting, as M. Bosquet observes, a smaller and shorter variety of the Bordeaux species.

So far as the shells of the Bolderberg are known, the proportion of recent species agrees with that in the faluns of Touraine, and the climate must have been warmer than that of the Coralline Crag of England.

Fig. 149.



Oliva Dufresnii, Bast Bolderberg, Belgi natural size. *a*, front view; *b*, back view.

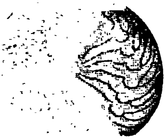
Upper Miocene beds of the Vienna basin.—In South Germany the general resemblance of the shells of the Vienna tertiary basin to those of the faluns of Touraine has long been acknowledged. In the late Dr. Hörnes' excellent work on the fossil mollusca of that formation, we see accurate figures of many shells, clearly of the same species as those found in the falunian sands of Touraine.

According to Professor Suess, the most ancient and purely marine of the Miocene strata in this basin consist of sands, conglomerates, limestones, and clays, and they are inclined inwards, or from the borders of the trough towards the centre, their outcropping edges rising much higher than the newer beds, whether Miocene or Pliocene, which overlie them, and which occupy a smaller area at an inferior elevation above the sea. M. Hörnes has described no less than 500 species of gasteropods, of which he identifies one-fifth with living species of the Mediterranean, Indian, or African seas, but the proportion of existing species among the lamellibranchiate bivalves exceeds this average. Among many univalves agreeing with those of Africa on the eastern side of the Atlantic are *Cypræa sanguinolenta*, *Buccinum lyratum*, and *Oliva flammulata*. In the lowest marine beds of the Vienna basin the remains of several mammalia have been found, and among them a species of *Dinotherium*, a Mastodon of the *Trilophodon* family, a Rhinoceros (allied to *R. megarhinus*, Christol), also an animal of the hog tribe, *Listriodon*, Von Meyer, and a carnivorous animal of the canine family. The *Helix turonensis* (fig. 38. p. 32), the most common land shell of the French faluns, accompanies the above land animals. In a higher member of the Vienna Miocene series are found *Dinotherium giganteum* (fig. 139, p. 193), *Mastodon longirostris*, *Rhinoceros Schleiermacheri*, *Acerotherium incisivum*, and *Hippotherium gracile*, all of them equally characteristic of an

Upper Miocene deposit occurring at Eppelsheim in Hesse Darmstadt; a locality also remarkable as having furnished in latitude 49° 50′ N. the bone of a large ape of the Gibbon kind, the most northerly example yet discovered of a quadrumanous animal.

M. Alcide d'Orbigny has shown that the foraminifera of the Vienna basin differ alike from the Eocene and Pliocene species, and agree with those of the faluns, so far as the latter are known. Among the Vienna foraminifera the genus *Amphistegina* (fig. 150) is very characteristic, and is supposed by D'Archiac to take the same place among the Rhizopods of the Upper Miocene era which the Nummulites occupy in the Eocene period.

Fig. 150.



Amphistegina Hauerina, D'Orb. Upper Miocene strata, Vienna.

The flora of the Vienna basin exhibits some species which have a general range through the whole Miocene period, such as *Cinnamomum polymorphum* (fig. 141), and *C. Scheuchzeri*, also *Planera Richardi*, Mich. *Liquidambar europæum* (fig. 138, p. 191), *Juglans bilinica*, *Cassia ambigua*, and *C. lignitum*. Among the plants common to the Upper Miocene beds of Œningen in Switzerland are *Platanus aceroides* (fig. 144, p. 203), *Myrica vindobonensis*, and others.

Upper Miocene strata of Italy.—We are indebted to Signor Michelotti for a valuable work on the Miocene shells of Northern Italy. Those found in the hill called the Superga, near Turin, have long been known to correspond in age with the faluns of Touraine, and they contain so many species common to the Upper Miocene strata of Bordeaux as to lead to the conclusion that there was a free communication between the northern part of the Mediterranean and the Bay of Biscay in the Upper Miocene period. In the hills of which the Superga forms part the Tertiary strata pass down into the Lower Miocene presently to be described (p. 227).

Upper Miocene formations of Greece.—At Pikermi, near Athens, MM. Wagner and Roth have described a deposit in which they found the remains of the genera *Mastodon*, *Dinotherium*, *Hipparion*, two species of *Giraffe*, *Antelope*, and others, some living and some extinct. With them were also associated fossil bones of the *Semnopithecus*, showing that here, as in the South of France, the quadrumana were characteristic of this period. The whole fauna attests the former extension of a vast expanse of grassy plains where we have now the broken and mountainous country of Greece; plains, which were probably united with Asia Minor, spreading over the area where the deep Egean

Sea and its numerous islands are now situated. We are indebted to M. Gaudry, who visited Pikermi, for a treatise on these fossil bones, showing how many data they contribute to the theory of a transition from the mammalia of the Upper Miocene through the Pliocene and Pleistocene forms to those of living genera and species. For example, he recognised an ape intermediate between the living genera Semnopithecus and Macacus; a carnivore intermediate between the hyæna and the civet; a pachyderm (Hipparion) intermediate between the Anchitherium and the horse; and a ruminant intermediate between the goat and the antelope. One striking feature of the change of the fauna as contrasted with that of the Eocene era is the increased number of species of ruminants as compared to pachyderms. M. Gaudry considers the deposit at Pikermi as belonging to a somewhat newer part of the Upper Miocene than that of Eppelsheim above described.[1]

Upper Miocene of India. Siwâlik Hills.—The Siwâlik Hills lie at the southern foot of the Himalayan chain, rising to the height of 2,000 and 3,000 feet. Between the Jumna and the Ganges they consist of inclined strata of sandstone, shingle, clay, and marl. We are indebted to the indefatigable researches of Dr. Falconer and Sir Proby Cautley, continued for 15 years, for the discovery in these marls and sandstones of a great variety of fossil mammalia and reptiles, together with many freshwater shells. Out of 15 species of shells of the genera *Paludina*, *Melania*, *Ampullaria*, and *Unio*, all are extinct or unknown species with the exception of 4, which are still inhabitants of Indian rivers. Such a proportion of living to extinct mollusca agrees well with the usual character of an Upper Miocene or Falunian fauna, as observed in Touraine, or in the basin of Vienna and elsewhere.

The genera of mammalia point in the same direction. One of them, of the genus *Chalicotherium* (or *Anisodon* of Lartet), is a pachyderm intermediate between the *Rhinoceros* and *Anoplothere*, and characteristic of the Upper Miocene strata of Eppelsheim, and of the South of France. With it occurs also an extinct form of *Hippopotamus*, called *Hexaprotodon*, and a species of *Hippotherium* and pig; also two species of *Mastodon*, two of elephant, and three other elephantine proboscidians; none of them agreeing with any fossil forms of Europe, and being intermediate between the genera Elephas and Mastodon, constituting the sub-genus *Stegodon* of Falconer. With these are associated a monkey, allied to the *Semnopithecus entellus*, now living in the Himalaya, and many ruminants. Amongst these last, besides the giraffe, camel, antelope, stag, and others, we find a remarkable new type, the *Sivatherium*, a gigantic four-horned ruminant allied to *Antilocapra*, the Prongbuck of North America. There are also new forms of carnivora, both feline and canine, the *Machairodus* among the former, also hyænas, and a subursine form called the *Hyænarctos*, and a genus allied to the otter (*Enhydriodon*), of formidable size.

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[1] Gaudry, Considérations sur les Mammifères de l'Epoque Miocene, 1873.

The giraffe, camel, and a large ostrich may be cited as proofs that there were formerly extensive plains where now a steep chain of hills, with deep ravines, runs for many hundred miles east and west. Among the accompanying reptiles are several crocodiles, some of huge dimensions, and one not distinguishable, says Dr. Falconer, from a species now living in the Ganges (*C. Gangeticus*), and there is still another saurian which the same anatomist has identified with a species now inhabiting India. There was also an extinct species of tortoise of gigantic proportions (*Colossochelys Atlas*), the curved shell of which was twelve feet three inches long and eight feet in diameter, the entire length of the animal being estimated at eighteen feet, and its probable height seven feet.

Numerous fossils of the Siwâlik type have also been found in Perim Island, in the Gulf of Cambay, and among these a species of *Dinotherium*, a genus so characteristic of the Upper Miocene period in Europe.

Older Pliocene and Miocene formations in the United States.—Between the Alleghany Mountains, formed of older rocks, and the Atlantic, there intervenes, in the United States, a low region occupied principally by beds of marl, clay, and sand, consisting of the cretaceous and tertiary formations, and chiefly of the latter. The general elevation of this plain bordering the Atlantic does not exceed 100 feet, although it is sometimes several hundred feet high. Its width in the Middle and Southern States is very commonly from 100 to 150 miles. It consists, in the South, as in Georgia, Alabama, and South Carolina, almost exclusively of Eocene deposits; but in North Carolina, Maryland, Virginia, and Delaware more modern strata predominate, of the age of the English Crag and faluns of Touraine.[1]

In the Virginian sands, we find in great abundance a species of Astarte (*A. undulata*, Conrad), which resembles closely, and may possibly be a variety of, one of the commonest fossils of the Suffolk Crag (*A. Omalii*); the other shells also, of the genera

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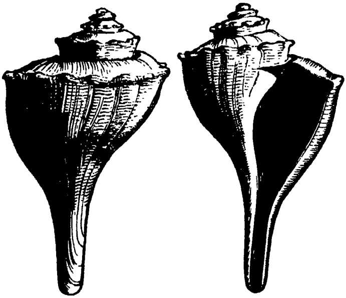
[1] Proceed. of the Geol. Soc., vol. iv. pt. 3, 1845, p. 547.

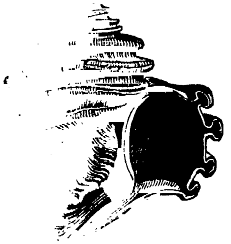
Natica, *Fissurella*, *Artemis*, *Lucina*, *Chama*, *Pectunculus*, and *Pecten*, are analogous to shells both of the English Crag and French faluns, although the species are almost all distinct. Out of 147 of these American fossils I could only find thirteen species

Fig. 151.



Fulgur Canaliculatus. Maryland.

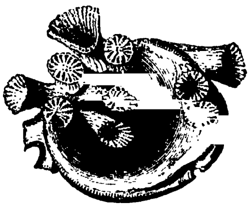
Fig. 152.



Fusus quadricostatus, Say. Maryland.

common to Europe, and these occur partly in the Suffolk Crag, and partly in the faluns of Touraine ; but it is an important characteristic of the American group, that it not only contains many peculiar extinct forms, such as *Fusus quadricostatus*, Say (see fig. 152), and *Venus tridacnoides*, abundant in these same formations, but also some shells which, like *Fulgur Carica* of Say and *F. canaliculatus* (see fig. 151), *Calyptræa costata*, *Venus mercenaria*, Lam., *Modiola glandula*, Totten, and *Pecten magellanicus*, Lam., are recent species, yet of forms now confined to the Western side of the Atlantic—a fact implying that some traces of the beginning of the present geographical distribution of mollusca date back to a period as remote as that of the Miocene strata.

Fig. 153.



Astrangia lineata, Lonsdale. Syn. *Anthophyllum lineatum*. Williamsburg, Virginia.

Of ten species of corals which I procured on the banks of the James River, one agrees generically with a coral now living on the coast of the United States. Mr. Lonsdale regarded these corals as indicating a temperature exceeding that of the Mediterranean, and the shells would lead to similar conclusions. Those occurring on the James River are in the 37th degree of N. latitude, while the French faluns are in the 47th; yet the forms of the American fossils would scarcely imply so warm a climate as must have prevailed in France when the Miocene strata of Touraine originated.

Among the remains of fish in these post-Eocene strata of the United States are several large teeth of the shark family, not distinguishable specifically from fossils of the faluns of Touraine.

CHAPTER XV.

LOWER MIOCENE.[1]

Lower Miocene strata of France—Line between Miocene and Eocene—Lacustrine strata of Auvergne—Fossil mammalia of the Limagne d'Auvergne—Lower Molasse of Switzerland—Dense conglomerates and proofs of subsidence—Flora of the Lower Molasse—American character of the Flora—Theory of a Miocene Atlantis—Lower Miocene of Belgium—Rupelian clay of Hermsdorf near Berlin—Mayence Basin—Lower Miocene of Croatia—Oligocene strata of Beyrich—Lower Miocene of Italy—Lower Miocene of England—Hempstead beds—Bovey Tracy lignites in Devonshire—Isle of Mull leaf-beds—Arctic Miocene Flora—Disco Island—Lower Miocene of United States—Fossils of Nebraska.

Boundary line between Miocene and Eocene formations.—The marine faluns of the valley of the Loire have been already described as resting in some places on a freshwater tertiary limestone, fragments of which have been broken off and rolled on the shores and in the bed of the Upper Miocene sea. Such pebbles are frequent at Pontlevoy on the Cher, with hollows drilled in them in which the perforating marine shells of the Falunian period still remain. Such a mode of superposition implies an interval of time between the origin of the freshwater limestone and its submergence beneath the waters of the Upper Miocene sea. The limestone in question forms a part of the formation called the Calcaire de la Beauce, which constitutes a large tableland between the basins of the Loire and the Seine. It is associated with marls and other deposits, such as may have been formed in marshes and shallow lakes in the newest part of a great delta. Beds of flint, continuous or in nodules, accumulated in these lakes, and aquatic plants, called *Charæ*, left their stems and seed-vessels imbedded both in the marl and flint, together with freshwater and land shells. Some of the siliceous rocks of this formation are used extensively for millstones. The flat summits or platforms of the hills round Paris, and large areas in the forest of Fontainebleau, as well as the Plateau de la Beauce, already alluded to, are chiefly composed of these freshwater strata. Next to these in the descending order are marine sands and sandstone, commonly called the Grès de Fontainebleau, from which a considerable number of shells, very distinct from those of the faluns, have been obtained at Étampes, south of Paris, and at Montmartre and other hills in Paris itself, or in its suburbs. At the bottom of these sands a green clay occurs, containing a small oyster, *Ostrea cyathula*, Lam., which, although of slight thickness, is spread over a wide area. This clay rests immediately on the Paris gypsum, or that series of beds of gypsum and gypseous marl from which Cuvier first obtained several species of Paleotherium and other extinct mammalia.[1]

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[1] Oligocene of Beyrich.

At this junction of the clay and the gypsum the majority of French geologists have always drawn the line between the Middle and Lower Tertiary, or between the Miocene and Eocene formations, regarding the Fontainebleau sands and the *Ostrea cyathula* clay as the base of the Miocene, and the gypsum with its mammalia as the top of the Eocene group. I formerly dissented from this division, but I now find that I must admit it to be the only one which will agree with the distribution of the Miocene mammalia, while even the mollusca of the Fontainebleau sands, which were formerly supposed to present a preponderance of affinities to an Eocene fauna, have since been shown to agree more closely with the fossils of certain deposits always regarded as Middle Tertiary at Mayence and in Belgium. In fact we are now arriving at that stage of progress when the line, wherever it be drawn between Miocene and Eocene, will be an arbitrary one, or one of mere convenience, as I shall have an opportunity of showing when the Upper Eocene formations in the Isle of Wight are described in the sixteenth chapter.

Lower Miocene of Central France.—Lacustrine strata, belonging, for the most part, to the same Miocene system as the Calcaire de la Beauce, are again met with further south in Auvergne, Cantal, and Velay. They appear to be the monuments of ancient lakes, which, like some of those now existing in Switzerland, once occupied the depressions in a mountainous region, and have been each fed by one or more rivers and torrents. The country where they occur is almost entirely composed of granite and different varieties of granitic schist, with here and there a few patches of Secondary strata, much dislocated, and which have suffered great denudation. There are also some vast piles of volcanic matter, the greater part of which is newer than the freshwater strata, and is sometimes seen to rest upon them, while a small part has evidently been of contemporaneous origin. Of these igneous rocks I shall treat more particularly in the sequel.

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[1] Bulletin, 1856, Journ. vol. xii. p. 768.

The study of these regions possesses a peculiar interest, very distinct in kind from that derivable from the investigation either of the Parisian or English tertiary areas. For we are presented in Auvergne with the evidence of a series of events of astonishing magnitude and grandeur, by which the original form and features of the country have been greatly changed, yet never so far obliterated but that they may still, in part at least, be restored in imagination. Great lakes have disappeared —lofty mountains have been formed by the reiterated emission of lava, preceded and followed by showers of sand and scoriæ—deep valleys have been subsequently furrowed out through masses of lacustrine and volcanic origin—at a still later date, new cones have been thrown up in these valleys—new lakes have been formed by the damming up of rivers—and more than one assemblage of quadrupeds, birds, and plants, Eocene, Miocene, and Pliocene, have followed in succession; yet the region has preserved from first to last its geographical identity; and we can still recall to our thoughts its external condition and physical structure before these wonderful vicissitudes began, or while a part only of the whole had been completed. There was first a period when the spacious lakes, of which we still may trace the boundaries, lay at the foot of mountains, of moderate elevation, unbroken by the bold peaks and precipices of Mont Dore, and unadorned by the picturesque outline of the Puy de Dome, or of the volcanic cones and craters now covering the granitic platform. During this earlier scene of repose deltas were slowly formed; beds of marl and sand, several hundred feet thick, deposited; siliceous and calcareous rocks precipitated from the waters of mineral springs; shells and insects imbedded together with the remains of the crocodile and tortoise, the eggs and bones of water-birds, and the skeletons of quadrupeds, most of them of genera and species characteristic of the Miocene period. To this tranquil condition of the surface succeeded the era of volcanic eruptions, when the lakes were drained, and when the fertility of the mountainous district was probably enhanced by the igneous matter ejected from below, and poured down upon the more sterile granite. During these eruptions, which appear to have taken place towards the close of the Miocene epoch, and which continued during the Pliocene, various assemblages of quadrupeds successively inhabited the district, amongst which are found the genera mastodon, rhinoceros, elephant, tapir, hippopotamus, together with the ox, various kinds of deer, the bear, hyæna, and many beasts of prey which ranged the forest, or pastured on the plain, and were occasionally overtaken by a fall of burning cinders, or buried in flows of mud, such as accompany volcanic eruptions. Lastly, these quadrupeds became extinct, and gave place in their turn to the species now existing. There are no signs, during the whole time required for this series of events, of the sea having intervened, nor of any denudation which may not have been accomplished by currents in the different lakes, or by rivers and floods accompanying repeated earthquakes, or subterranean movements, during which the levels of the district have in some places been materially modified, and perhaps the whole upraised relatively to the surrounding parts of France.

Auvergne.—The most northern of the freshwater groups is situated in the valley plain of the Allier, which lies within the department of the Puy de Dome, being the tract which went formerly by the name of the Limagne d'Auvergne. The average breadth of this tract is about twenty miles; and it is for the most part composed of nearly horizontal strata of sand, sandstone, calcareous marl, clay, and limestone, none of which observe a fixed and invariable order of superposition. The ancient borders of the lake, wherein the freshwater strata were accumulated, may generally be traced with precision, the granite and other ancient rocks rising up boldly from the level country. The actual junction, however, of the lacustrine beds and the granite is rarely seen, as a small valley usually intervenes between them. The freshwater strata may sometimes be seen to retain their horizontality within a very slight distance of the border-rocks, while in some places they are inclined, and in a few instances vertical. The principal divisions into which the lacustrine series may be separated are the following:—1st, Sandstone, grit, and conglomerate, including red marl and red sandstone; 2ndly, Green and white foliated marls; 3rdly, Limestone, or travertin, often oolitic in structure; 4thly, Gypseous marls.

The relations of these different groups cannot be learnt by the study of any one section; and the geologist who sets out with the expectation of finding a fixed order of succession may perhaps complain that the different parts of the basin give contradictory results. The arenaceous division, the marls, and the limestone may all be seen in some places to alternate with each other; yet it can by no means be affirmed that there is no order of arrangement. The sands, sandstone, and conglomerate constitute in general a littoral group; the foliated white and green marl, a contemporaneous central deposit more than 700 feet thick, and thinly foliated, a character which often arises from the innumerable thin shells or carapace valves shed by the small crustacean called *Cypris* in the ancient lakes of Auvergne ; and lastly the limestone is for the most part subordinate to the newer portions of both the above formations.

It seems that, when the ancient lake of the Limagne first began to be filled with sediment, no volcanic action had yet produced lava and scoriæ on any part of the surface of Auvergne. No pebbles, therefore, of lava were transported into the lake—no fragments of volcanic rocks embedded in the conglomerate. But at a later period, when a considerable thickness of sandstone and marl had accumulated, eruptions broke out, and larva and tuff were deposited, at some spots, alternately with the lacustrine strata. It is not improbable that both cold and hot springs, holding different mineral ingredients in solution, became more numerous during the successive convulsions attending this development of volcanic agency, and thus deposits of carbonate and sulphate of lime, silex, and other minerals were produced. Hence these minerals predominate in the uppermost strata. The subterranean movements may then have continued until they altered the relative levels of the country, and caused the waters of the lakes to be drained off, and the farther accumulation of regular freshwater strata to cease.

Lower Miocene mammalia of the Limagne.—It is scarcely possible to determine the age of the oldest part of the freshwater series of the Limagne, large masses both of the sandy and marly strata being devoid of fossils. Some of the lowest beds may be of Upper Eocene date, although, according to M. Pomel, only one bone of a *Palæotherium* has been discovered in Auvergne. But in Vélay, in strata containing some species of fossil mammalia common to the Limagne, no less than four species of Palæothere have been found by M. Aymard, and one of these is generally supposed to be identical with *Palæotherium magnum*, an undoubted Upper Eocene fossil, of the Paris gypsum, the other three being peculiar.

Not a few of the other mammalia of the Limagne belong undoubtedly to genera and species elsewhere proper to the Lower Miocene. Thus, for example, the Cainotherium of Bravard, a genus not far removed from the Anoplotherium, is represented by several species, one of which, as I learn from Mr. Waterhouse, agrees with *Microtherium Renggeri* of the Mayence basin. In like manner the *Amphitragulus elegans* of Pomel, an Auvergne fossil, is identified by Waterhouse with *Dorcatherium nanum* of Kaup, a Rhenish species from Weissenau, near Mayence. A small species also of rodent, of the genus Titanomys of H. von Meyer, is common to the Lower Miocene of Mayence and the Limagne d'Auvergne, and there are many other points of agreement which the discordance of nomenclature tends to conceal. A remarkable carnivorous genus, the Hyænodon of Laizer, is represented by more than one species. The same genus has also been found in the Upper Eocene marls of Hordwell Cliff, Hampshire, just below the level of the Bembridge Limestone, and therefore a formation older than the Gypsum of Paris. Several species of opossum (*Didelphis*) are met with in the same strata of the Limagne. The total number of mammalia enumerated by M. Pomel as appertaining to the Lower Miocene fauna of the Limagne and Vélay, falls little short of a hundred, and with them are associated some large crocodiles and tortoises, and some Ophidian and Batrachian reptiles. The birds of the Limagne and those of the Mayence basin are, according to Mr. Milne Edwards, almost identical. Among these, in the Limagne, are extinct species of duck, stork, and many of the swallow tribe.

Lower Molasse of Switzerland.—The two upper divisions of the Swiss Molasse—the one freshwater, the other marine—have already been described in the preceding chapter. I shall now proceed to treat of the third division, which is of Lower Miocene age. Nearly the whole of this Lower Molasse is freshwater; yet some of the inferior beds contain a mixture of marine and fluviatile shells, the *Cerithium margaritaceum*, a well-known Lower Miocene fossil, being one of the marine species. Notwithstanding, therefore, that some of these Lower Miocene strata consist of old shingle beds several thousand feet in thickness, as in the Rigi near Lucerne, and in the Speer near Wesen, mountains 5,000 and 7,000 feet above the sea, the deposition of the whole series must have begun at or below the sea-level.

The conglomerates, as might be expected, are often very unequal in thickness, in closely adjoining districts, since in a littoral formation accumulations of pebbles would swell out in certain places where rivers entered the sea, and would thin out to comparatively small dimensions where no streams, or only small ones, came down to the coast. For ages, in spite of a gradual depression of the land and adjacent sea-bottom, the rivers continued to cover the sinking area with their deltas; until finally, the subsidence being in excess, the sea of the Middle Molasse gained upon the land, and marine beds were thrown down over the dense mass of freshwater and brackish-water deposit, called the Lower Molasse, which had previously accumulated.

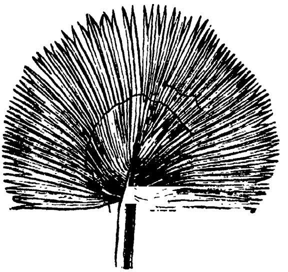
Flora of the Lower Molasse.—In part of the Swiss Molasse which belongs exclusively to the Lower Miocene Period, the number of plants has been estimated at more than 500 species, somewhat exceeding those which were before enumerated as occurring in the two upper divisions. The Swiss Lower Miocene may best be studied on the northern borders of the Lake of Geneva between Lausanne and Vevay, where the contiguous villages of Monod and Rivaz are situated. The strata there, which I have myself examined, consist of alternations of conglomerate, sandstone, and finely laminated marls with fossil plants. A small stream falls in a succession of cascades over the harder beds of pudding-stone, which resist, while the sandstone and plant-bearing shales and marls give way. From the latter no less than 193 species of plants have been obtained by the exertions of MM. Heer and Gaudin, and they are considered to afford a true type of the vegetation of the Lower Miocene formations of Switzerland—a vegetation departing farther in its character from that now flourishing in Europe than any of the higher members of the series before alluded to, and yet displaying so much affinity to the flora of Œningen as to make it natural for the botanist to refer the whole to one and the same Miocene period. There are, indeed, no less than 81 species of these Older Miocene plants which pass up into the flora of Œningen.

This fact is important as bearing on the propriety of classifying the Lower Molasse of Switzerland as belonging to the Miocene rather than to the latter part of the Eocene period. There are, indeed, so many types among the fossils both specific and generic which have a wide range through the whole of the Molasse, that a unity of character is thereby stamped on the whole flora, in spite of the contrast between the plants of the uppermost and lowest formations, or between Œningen and Monod. The proofs of a warmer climate and the excess of arborescent over herbaceous plants and of evergreen trees over deciduous species, are characters common to the whole flora, but which are intensified as we descend to the inferior deposits.

Nearly all the plants at Monod are contained in three layers of marl separated by two of soft sandstone. The thickness of the marls is ten feet, and vegetable matter predominates so much in some layers as to form an imperfect lignite. One bed is filled with large leaves of a species of fig (*Ficus populina*), and of a hornbeam (*Carpinus grandis*), the strength of the wind having probably been great when they were blown into the lake; whereas another contiguous layer contains almost exclusively smaller leaves, indicating, apparently, a diminished strength in the wind. Some of the upper beds at Monod abound in leaves of Proteaceæ, Cyperaceæ, and ferns, while in some of the lower ones *Sequoia*, *Cinnamomum*, and *Sparganium* are common. In one bed of sandstone the trunk of a large palm tree was found unaccompanied by other fossils, and near Vevay, in the same series or Lower Miocene strata, the leaves of a fan-palm of the genus *Sabal* (fig. 154), a genus now proper to North America, were obtained.

Among other genera of the same class is a *Flabellaria* occurring near Lausanne, and a magnificent *Phœnicites* allied to the date-palm. When these plants flourished the climate must have been much hotter than now. The Alps were no doubt much lower, and the palms now found fossil in strata elevated 2,000 feet above the sea grew nearly at the sea-level, as is demonstrated by the brackish-water character of some of the beds into which they were carried by winds or rivers from the adjoining coast.

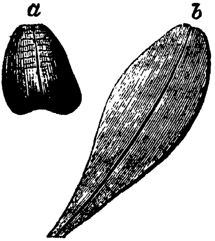
Fig. 154.



l major, Ungor sp. Vevay, Lower Miocene. (Heer, Pl. 41.)

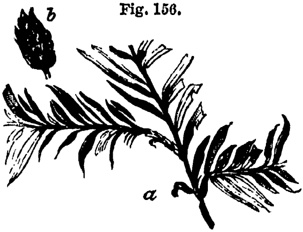
In the same plant-bearing deposits of the Lower Molasse in Switzerland leaves have been found which have been ascribed to the order Proteaceæ already spoken of as well represented in the Œningen beds (see p. 203). The Proteas and other plants of this family now flourish at the Cape of Good Hope ; while the Banksias, and a set of genera distinct from those of Africa, grow most luxuriantly in the southern and temperate parts of Australia. They were probably inhabitants, says Heer, of dry hilly ground ; and the stiff leathery character of their leaves must have been favourable to their preservation, allowing them to float on a river for great distances without being injured and then to sink, when water-logged, to the bottom. It has been objected that the fruit of the Proteaceæ is of so tough and enduring a texture that it ought to have been more commonly met with ; but in the first place we must not forget the numerous cones found in the Eocene strata of Sheppey, which all admit to be proteaceous and to belong to at least two species (see p. 248). Secondly, besides the fruit of Hakea before mentioned (p. 204), Heer found associated with fossil leaves, having the exact form and nervation of Banksia, fruit precisely such as may have come from a cone of that plant, and lately he has received another similar fruit from the Lower Miocene strata of Lucerne. They may have fallen out of a decayed cone in the same way as often happens to the seeds of the spruce fir, *Pinus abies*, found scattered over the ground in our woods. It is a known fact that among the living Proteaceæ the cones are very firmly attached to the branches, so that the seeds drop out without the cone itself falling to the ground; and this may perhaps be the reason why, in some instances in which fossil seeds have been found, no traces of the cone have been observed.

Fig. 155.



a. Fruit of a fossil Banksia.
b. Leaf of Banksia Deekiana.

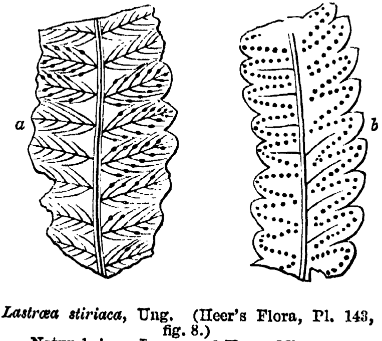
Fig. 156.



Sequoia Langsdorfii. Ad. Brong, ⅓ natural size. Rivaz, near Lausanne. (Heer, Pl. 21, fig. 4.) Upper and Lower Miocene and Lower Pliocene, Val d'Arno.

a. Branch with leaves. *b.* Young cone.

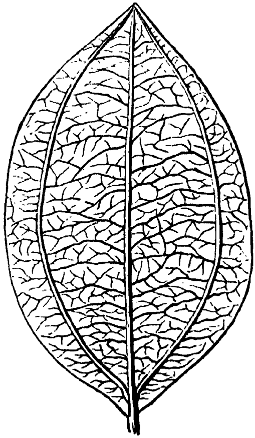
Fig. 157.



Lastræa stiriaca, Ung. (Heer's Flora, Pl. 143, fig. 8.)
Natural size. Lower and Upper Miocene. Switzerland.

a. Specimen from Monod, showing the position of the sori on the middle of the tertiary nerves.
b. More common appearance, where the sori remain and the nerves are obliterated.

Fig. 158.



Cinnamomum Rossmassleri, Heer. *Daphnogene cinnamomifolia,* Unger. Upper and Lower Miocene Switzerland and Germany.

Among the Coniferæ the *Sequoia* (fig. 156) is common at Rivaz, and is one of the most universal plants in the Lowest Miocene of Switzerland, while it also characterises the Miocene Brown Coals of Germany and certain beds of the Val d'Arno, which I have called Older Pliocene, p. 189.

Among the ferns met with in profusion at Monod is the *Lastræa stiriaca*, Unger, which has a wide range in the Miocene period from strata of the age of Œningen to the lowest part of the Swiss molasse. In some specimens, as shown in figure 157, the fructification is distinctly seen.

Among the laurels several species of *Cinnamomum* are very conspicuous. Besides *C. polymorphum*, before figured, p. 201, another species also ranges from the Lower to the Upper Molasse of Switzerland, and is very characteristic of different deposits of Brown Coal in Germany. It has been called *Cinnamomum Rossmässleri* by Heer (see fig. 158). The leaves are easily recognised as having two side veins, which run up uninterruptedly to their point.

American character of the flora.—If we consider not merely the number of species but those plants which constitute the mass of the Lower Miocene vegetation, we find the European part of the fossil flora very much less prominent than in the Œningen beds, while the foreground is occupied by American forms, by evergreen oaks, maples, poplars, planes, Liquidambar, Robinia, Sequoia, Taxodium, and ternate-leaved pines. There is also a much greater fusion of the characters now belonging to distinct botanical provinces than in the Upper Miocene flora, and we shall find this fusion still more strikingly exemplified as we go back to the antecedent Eocene and Cretaceous periods.

Professor Heer has advocated the doctrine, first advanced by Unger to explain the large number of American genera in the Miocene flora of Europe, that the present basin of the Atlantic was occupied by land over which the Miocene flora could pass freely. But other able botanists have shown that it is far more probable that the American plants came from the east and not from the west, and, instead of reaching Europe by the shortest route over an imaginary Atlantis, migrated in an opposite direction crossing the whole of Asia.

Arctic Miocene Flora.—But when we indulge in speculations as to the geographical origin of the Miocene plants of Central Europe, we must take into account the discoveries recently made of a rich terrestrial flora having flourished in the Arctic regions in the Miocene period from which many species may have migrated from a common centre so as to reach the present continents of Europe, Asia, and America. Professor Heer has examined the various collections of fossil plants that have been obtained in N. Greenland (lat. 70°), Iceland, Spitzbergen, and other parts of the Arctic regions, and has determined that they are of Miocene age and indicate a temperate climate.[1] Including the collections recently brought from Greenland by Mr. Whymper, the Arctic Miocene flora now comprises 194 species, and that of Greenland 137 species, of which 46, or exactly one-third, are identical with plants found in the Miocene beds of Central Europe. Considerably more than half the number are trees, which is the more remarkable since at the present day trees do not exist in any part of Greenland even 10° farther south.

More than 30 species of Coniferæ have been found, including several Sequoias (allied to the gigantic Wellingtonia of California), with species of Thujopsis and Salisburia now peculiar to Japan. There are also beeches, oaks, planes, poplars, maples, walnuts, limes, and even a magnolia, two cones of which have recently been obtained, proving that this splendid tree not only lived but ripened its fruit within the Arctic circle. Many of the limes, planes, and oaks were large-leaved species, and both flowers and fruit, besides immense quantities of leaves, are in many cases preserved. Among the shrubs were many evergreens, as *Andromeda*, and two extinct genera, *Daphnogene* and *M'Clintockia*, with fine leathery leaves, together with hazel, blackthorn, holly, logwood, and hawthorn. *Potomogeton*, *Sparganium*, and *Menyanthes* grew in the swamps, while ivy and vines twined around the forest trees, and broad-leaved ferns grew beneath their shade. Even in Spitzbergen, as far north as lat. 78° 56′, no less than 131 species of fossil plants have been obtained, including *Taxodium* of two species, hazel, poplar, alder, beech, plane-tree, and lime.[2] Such a vigorous growth of trees within 12° of the pole, where now a dwarf willow and a few herbaceous plants form the only vegetation, and where the ground is covered with almost perpetual snow and ice, is truly remarkable.

The identity of so many of the fossils with Miocene species of Central Europe and Italy not only proves that the climate of Greenland was much warmer than it is now, but also rendersit probable that a much more uniform climate prevailed over the entire northern hemisphere. This is also indicated by the whole character of the Upper Miocene Flora of Central Europe, which does not necessitate a mean temperature very much greater than exists at present, if we suppose such absence of winter cold as is proper to insular climates. Professor Heer believes that the mean temperature of North Greenland must have been at least 30° higher than at present, while an addition of 10° to the mean temperature of Central Europe would probably be as much as was required. The chief locality where this wonderful flora is preserved is at Atanekerdluk in North Greenland (lat. 70°), on a hill at an elevation of about 1,200 feet above the sea. There is here a considerable succession of sedimentary strata pierced by volcanic rocks. Fossil plants occur in all the beds; and the erect trunks as thick as a man's body which are sometimes found, together with the abundance of specimens of flowers and fruit in good preservation, sufficiently prove that the plants grew where they are now found. At Disco island and other localities on the same part of the coast, good tertiary coal is abundant, interstratified with beds of sandstone in some of which fossil plants have also been found, similar to those at Atanekerdluk.

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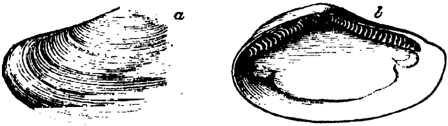
[1] Heer, 'Flora Fossilis Arctica,' and 'Fossil-Flora von Alaska,' 1869.

[2] Heer, 'Miocene Flora and Fauna of Spitzbergen.' Stockholm, 1870.

Lower Miocene, Belgium.—The upper Miocene Bolderberg beds, mentioned at p. 206, rest on a Lower Miocene formation called the Rupelian of Dumont. This formation is best seen at the villages of Rupelmonde and Boom, ten miles south of Antwerp, on the banks of the Scheldt, and near the junction with it of a small stream called the Rupel. A stiff clay abounding in fossils is extensively worked at the above localities for making tiles. It attains a thickness of about 100 feet, and, though very different in age, much resembles in mineral character the 'London Clay,' containing, like it, septaria or concretions of argillaceous limestone traversed by cracks in the interior, which are filled with calc-spar. The shells, referable to about forty species, have been described by MM. Nyst and De Koninck. Among them *Leda* (or *Nucula*) *Deshayesiana* (see fig. 159) is by far the most abundant; a fossil unknown as yet in the English tertiary strata, but when young much resembling *Leda amygdaloides* of the London Clay proper (see fig. 216, p. 249). Among other characteristic shells are *Pecten Hœninghausii*, and a species of *Cassidaria*, and several of the genus *Pleurotoma*. Not a few of these testacea agree with English

Fig. 159.



Leda (Nucula) Deshayesiana, Nyst.

Eocene species, such as *Actæon simulatus*, Sow., *Cancellaria evulsa*, Brander, *Corbula pisum* (fig. 161), and *Nautilus* (*Aturia*) *ziczac*. They are accompanied by many teeth of sharks, as *Lamna contortidens*, Ag., *Oxyrhina xiphodon*, Ag., *Carcharodon angustidens* (see fig. 199, p. 245), Ag., and other fish, some of them common to the Middle Eocene strata.

Kleyn Spawen beds.—The succession of the Lower Miocene strata of Belgium can be best studied in the environs of Kleyn Spawen, a village situated about seven miles west of Maestricht, in the old province of Limburg, in Belgium. In that region, about 200 species of testacea, marine and freshwater, have been obtained, with many foraminifera and remains of fish. In none of the Belgian Lower Miocene strata could I find any nummulites; and M. d'Archiac had previously observed that these foraminifera characterise his 'Lower Tertiary Series,' as contrasted with the Middle, and they therefore serve as a good test of age between Eocene and Miocene, at least in Belgium and the North of France.[1] Between the Bolderberg beds and the Rupelian clay there is a great gap in Belgium, which seems, according to M. Beyrich, to be filled up in the North of Germany by what he calls the Sternberg beds, and which, had Dumont found them in Belgium, he might probably have termed Upper Rupelian.

Lower Miocene of Germany.—*Rupelian Clay of Hermsdorf, near Berlin.*—Professor Beyrich has described a mass of clay, used for making tiles, within seven miles of the gates of Berlin, near the village of Hermsdorf, rising up from beneath the sands with which that country is chiefly overspread. This clay is more than forty feet thick, of a dark bluish-grey colour, and, like that of Rupelmonde, contains septaria. Among other shells, the *Leda Deshayesiana*, before mentioned (fig. 159), abounds, together with many species of *Pleurotoma*, *Voluta*, &c., a certain proportion of the fossils being identical in species with those of Rupelmonde.

Mayence basin.—An elaborate description has been published by Dr. F. Sandberger of the Mayence tertiary area, which occupies a tract from five to twelve miles in breadth, extending for a great distance along the left bank of the Rhine from Mayence to the neighbourhood of Manheim, and which is also found to the east, north, and south-west of Frankfort. M. de Koninck, of Liége, first pointed out to me that the purely marine portion of the deposit contained many species of shells common to the Kleyn Spawen beds, and to the clay of Rupelmonde, near Antwerp. Among these he mentioned *Cassidaria*

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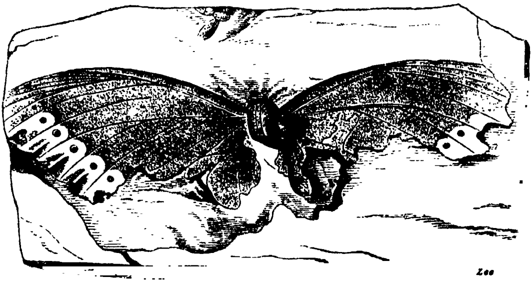
[1] D'Archiac, Monogr., pp. 79, 100.

depressa, *Tritonium argutum*, Brander (*T. flandricum*, De Koninck), *Tornatella simulata*, *Aporrhais Sowerbyi*, *Leda Deshayesiana* (fig. 159), *Corbula pisum* (fig. 161, p. 228), and others.

Lower Miocene beds of Croatia.—The Brown Coal of Radaboj, near Agram, in Croatia, not far from the borders of Styria, is covered, says Von Buch, by beds containing the marine shells of the Vienna basin, or, in other words, by Upper Miocene or Falunian strata. They appear to correspond in age to the Mayence basin, or to the Rupelian strata of Belgium. They have yielded more than 200 species of fossil plants, described by the late Professor Unger. These plants are well preserved in a hard marlstone, and contain several palms; among them the Sabal (fig. 154, p. 220), and another genus allied to the date-palm, *Phœnicites spectabilis*. The only abundant plant among the Radaboj fossils which is characteristic of the Upper Miocene period is the *Populus mutabilis*, whereas no less than fifty of the Radaboj species are common to the more ancient flora of the Lower Molasse of Switzerland.

The insect fauna is very rich, and, like the plants, indicates a more tropical climate than do the fossils of Œningen presently to be mentioned. There are ten species of Termites, or white ants, some of gigantic size, and large dragon-flies with speckled wings, like those of the Southern States in North America; there are also grasshoppers of considerable size, and even the Lepidoptera are not unrepresented. In one instance, the pattern of a butterfly's wing has escaped obliteration in the marlstone of Radaboj; and when we reflect on the remoteness of the time from which it has been faithfully transmitted to us, this fact may inspire the reader with some confidence as to the

Fig. 160.



Vanessa Pluto; nat. size. Lower Miocene, Radaboj, Croatia.

reliable nature of the characters which other insects of a more durable texture, such as the beetles, may afford for specific determination. The Vanessa (fig. 160) retains, says Heer, some of its colours, and corresponds with *V. Hadena* of India.

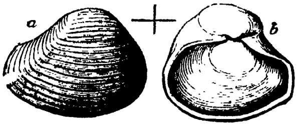
Professor Beyrich has made known to us the existence of a long succession of marine strata in North Germany, which lead by an almost gradual transition from beds of Upper Miocene age to others of the age of the base of the Lower Miocene. Although some of the German lignites called Brown Coal belong to the upper parts of this series, the most important of them are of Lower Miocene date, as, for example, those of the Siebengebirge, near Bonn, which are associated with volcanic rocks. Professor Beyrich confines the term 'Miocene' to those strata which agree in age with the faluns of Touraine, and he has proposed the term 'Oligocene' for those older formations called Lower Miocene in this work.

Lower Miocene of Italy.—In the hills of which the Superga forms a part (see above, p. 208) there is a great series of Tertiary strata which pass downwards into the Lower Miocene. Even in the Superga itself there are some fossil plants which, according to Heer, have never been found in Switzerland so high as the marine Molasse, such as *Banksia longifolia*, and *Carpinus grandis*. In several parts of the Ligurian Apennines, as at Dégo and Carcare, the Lower Miocene appears, containing some nummulites, and at Cadibona, north of Savona, freshwater strata of the same age occur, with dense beds of lignite enclosing remains of the *Anthracotherium magnum* and *A. minimum*, besides other mammalia enumerated by Gastaldi. In these beds a great number of the Lower Miocene plants of Switzerland have been discovered.

Lower Miocene of England—Hempstead beds.—We have already stated that the Upper Miocene formation is nowhere represented in the British Isles; but strata referable to the Lower Miocene period are found both in England, Scotland, and Ireland. In the Hampshire basin these occupy a very small superficial area, having been discovered by the late Edward Forbes at Hempstead near Yarmouth, in the northern part of the Isle of Wight, where they are 170 feet thick, and rich in characteristic marine shells. They overlie the uppermost of an extensive series of Eocene deposits of marine, brackish, and freshwater formations, which rest on the Chalk and terminate upwards in strata corresponding in age to the Paris gypsum, and containing the same extinct genera of quadrupeds, *Palæotherium*, *Anoplotherium*, and others which Cuvier first described. The following is the succession of these Lower Miocene strata, most of them exposed in a cliff east of Yarmouth.

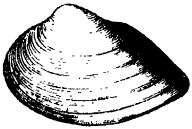
1. The uppermost or Corbula beds, consisting of marine sands and clays, contain *Voluta Rathieri*, a characteristic Lower Miocene shell; *Corbula pisum* (fig. 161), a species common to the Upper Eocene clay of Barton; *Cyrena semistriata* (fig. 162), several *Cerithia*, and other shells peculiar to this series.

Fig. 161.



Corbula pisum. Hempstead Beds, Isle of Wight.

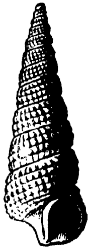
Fig. 162.



Cyrena semistriata. Hempstead Beds.

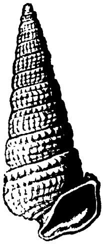
2. Next below are freshwater and estuary marls and carbonaceous clays, in the brackish-water portion of which are found abundantly *Cerithium plicatum*, Lam. (fig. 163), *C. elegans* (fig. 164), and *C. tricinctum*; also *Rissoa Chastelii* (fig. 165), a very common Kleyn Spawen shell, which occurs in each of the four subdivisions of the Hempstead series down to its base, where it passes into the Bembridge beds. In the freshwater portion of the same beds *Paludina lenta* (fig. 166) occurs; a shell identified by some conchologists with a species now living, *P. unicolor*; also several species of *Limnæus*, *Planorbis*, and *Unio*.

Fig. 163.



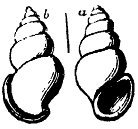
Cerithium plicatum, Lam. Hempstead.

Fig. 164.



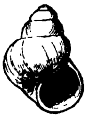
Cerithium elegans. Hempstead.

Fig. 165.



Rissoa Chastelii, Nyst, Sp. Hempstead, Isle of Wight.

Fig. 166.



Paludina lenta. Hempstead Bed.

3. The next series, or middle freshwater and estuary marls, are distinguished by the presence of *Melania fasciata*, *Paludina*

lenta, and clays with *Cypris*; the lowest bed contains *Cyrena semistriata* (fig. 162), mingled with *Cerithia* and a *Panopæa*.

4. The lower freshwater and estuary marls contain *Melania costata*, Sow., *Melanopsis*, &c. The bottom bed is carbonaceous, and called the 'Black band,' in which *Rissoa Chastelii* (fig. 165), before alluded to is common. This bed contains a mixture of Hempstead shells with those of the underlying Upper Eocene or Bembridge series. The mammalia, among which is *Hyopotamus bovinus*, differ, so far as they are known, from those of the Bembridge beds. The *Hyopotamus* belongs to the hog tribe, or the same family as the Anthracotherium, of which seven species, varying in size from the hippopotamus to the wild boar, have been found in Italy and other parts of Europe associated with the lignites of the Lower Miocene period.

Among the plants, Professor Heer has recognised four species common to the lignite of Bovey Tracey (a Lower Miocene formation presently to be described): namely *Sequoia Couttsiæ*, Heer; *Andromeda reticulata*, Ettingsh.; *Nelumbium* (*Nymphæa*) *Doris*, Heer; and *Carpolithes Websteri*, Brong.[1] The seed-vessels of *Chara medicaginula*, Brong., and *C. helicteres* are characteristic of the Hempstead beds generally.

Lignites and Clays of Bovey Tracey, Devonshire.—Surrounded by the granite and other rocks of the Dartmoor hill in Devonshire, is a formation of clay, sand, and lignite, long known to geologists as the Bovey Coal formation, respecting the age of which, until the year 1861, opinions were very unsettled. This deposit is situated at Bovey Tracey, a village distant eleven miles from Exeter in a south-west, and about as far from Torquay in a north-west, direction. The strata extend over a plain nine miles long, and they consist of the materials of decomposed and worn-down granite mixed with vegetable matter, and have evidently filled up an ancient hollow or lake-like expansion of the valleys of the Bovey and Teign.

The lignite is of bad quality for economical purposes, having a great admixture of iron pyrites, and emitting a sulphurous odour; it has, however, been successfully applied to the baking of pottery, for which some of the fine clays are well adapted. Mr. Pengelly has confirmed Sir H. De la Beche's opinion that much of the upper portion of this old lacustrine formation has been removed by denudation.[2]

At the surface is a dense covering of white clay and gravel with angular stones probably of the Pleistocene period, for in the clay are three species of willow and the dwarf birch, *Betula nana, indicating a climate colder than that of Devonshire at the present day.*

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[1] Pengelly, preface to 'The Lignite Formation of Bovey Tracey,' p. xvii.: London, 1863.

[2] Phil. Trans., 1863. Paper by W. Pengelly, F.R.S., and Dr. Oswald Heer.

Below this are Lower Miocene strata about 300 feet in thickness, in the upper part of which are twenty-six beds of lignite, clay, and sand, and at their base a ferruginous quartzose sand, varying in thickness from two to twenty-seven feet. Below this sand are forty-five beds of alternating lignite and clay. No shells or bones of mammalia, and no insect, with the exception of one fragment of a beetle (*Bupestris*); in a word, no organic remains, except plants, have as yet been found. These plants occur in fourteen of the beds; namely, in two of the clays, and the rest in the lignites. One of the beds is a perfect mat of the débris of a coniferous tree, called by Heer *Sequoia Couttsiæ*, intermixed with leaves of ferns. The same Sequoia (before mentioned as a Hempstead fossil, p. 229) is spread through all parts of the formation, its cones, and seeds, and branches of every age being preserved. It is a species supplying a link between *S. Langsdorfii* (see fig. 156, p. 221) and *S. Sternbergi*, the widely spread fossil representatives of the two living trees *S. Sempervirens* and *S. gigantea* (or Wellingtonia), both now confined to California. Another bed is full of the large rhizomes of ferns, while two others are rich in dicotyledonous leaves. In all, Professor Heer enumerates forty-nine species of plants, twenty of which are common to the Miocene beds of the Continent, a majority of them being characteristic of the Lower Miocene. The new species, also of Bovey, are allied to plants of the older Miocene deposits of Switzerland, Germany, and other Continental countries. The grape-stones of two species of vine occur in the clays, and leaves of the fig, and seeds of a water-lily. The oak and laurel have supplied many leaves. Of the triple-nerved laurels several are referred to Cinnamomum. There are leaves also of a palm of which the genus is not determined. Leaves also of protaceous forms, like some of the Continental fossils before mentioned, occur, and ferns like the well-known *Lastræa stiriaca* (fig. 157, p. 221), displaying at Bovey as in Switzerland its fructification.

The croziers of some of the young ferns are very perfect, and were at first mistaken by collectors for shells of the genus *Planorbis*. On the whole, the vegetation of Bovey implies the existence of a sub-tropical climate in Devonshire, in the Lower Miocene period.

Scotland.—Isle of Mull.—In the sea-cliffs, forming the headland of Ardtun, on the west coast of Mull, in the Hebrides, several bands of tertiary strata containing leaves of dicotyledonous plants were discovered in 1851 by the Duke of Argyll.[1] From his description it appears that there are three leaf-beds, varying in thickness from 1½ to 2½ feet, which are interstratified with volcanic tuff and trap, the whole mass being about 130 feet in thickness. A sheet of basalt 40 feet thick covers the whole; and another columnar bed of the same rock, 10 feet thick, is exposed at the bottom of the cliff. One of the leaf-beds consists of a compressed mass of leaves unaccompanied by any stems, as if they had been blown into a marsh where a species of *Equisetum* grew, of which the remains are plentifully embedded in clay.

It is supposed by the Duke of Argyll that this formation was accumulated in a shallow lake or marsh in the neighbourhood of a volcano, which emitted showers of ashes and streams of lava. The tufaceous envelope of the fossils may have fallen into the lake from the air as volcanic dust, or have been washed down into it as mud from the adjoining land. Even without the aid of Tertiary fossil plants, we might have decided that the deposit was newer than the chalk, for chalk flints containing cretaceous fossils were detected by the Duke in the principal mass of volcanic ashes or tuff.[2]

The late Edward Forbes observed that some of the plants of this formation resembled those of Croatia, described by Unger; and his opinion has been confirmed by Professor Heer, who found that the conifer most prevalent was the *Sequoia Langsdorfii* (fig. 156, p. 221), also *Corylus grosse-dentata*, a Lower Miocene species of Switzerland and of Menat, in Auvergne. There is likewise a plane tree, the leaves of which seem to agree with those of *Platanus aceroides* (fig. 144, p. 203), and a fern, *Filicites hebridica*, Forbes, which is as yet peculiar as a European fossil to Mull, but which is considered by Newberry to be identical with a living American species, *Onoclea sensibilis*.

These interesting discoveries in Mull led geologists to suspect that the basalt of Antrim and of the Giant's Causeway, in Ireland, might be of the same age. The volcanic rocks that overlie the chalk, and some of the strata associated with and interstratified between masses of basalt, contain leaves of dicotyledonous plants, somewhat imperfect, but resembling the beech, oak, and plane, and also some coniferæ of the genera pine and Sequoia. The general dearth of strata in the British Isles, intermediate in age between the formation of the Eocene and Pliocene periods, may arise, says Professor Forbes, from the extent of dry land which prevailed in that vast interval of time. If land predominated, the only monuments we are likely ever to find of Miocene date are those of lacustrine and volcanic origin, such as the Bovey Coal in Devonshire, the Ardtun beds in Mull, or the lignites and associated basalts in Antrim.

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[1] Quart. Geol. Journal, 1851, p. 19.

[2] Ibid, p. 90.

Lower Miocene, United States.—*Nebraska.*—In the territory of Nebraska, on the Upper Missouri, near the Platte River, lat. 42° N., a Tertiary formation occurs, consisting of white limestone, marls, and siliceous clay, described by Dr. D. Dale Owen,[1] in which many bones of extinct quadrupeds, and of chelonians of land or freshwater forms, are met with. Among these, Dr. Leidy describes a gigantic quadruped, called by him *Titanotherium*, nearly allied to the *Palæotherium*, but larger than any of the species found in the Paris gypsum. With these are several species of the genus *Oreodon*, Leidy, uniting the characters of pachyderms and ruminants; *Eucrotaphus*, another new genus of the same mixed character; two species of rhinoceros of the sub-genus *Acerotherium*, a Lower Miocene form of Europe before mentioned; two species of *Archæotherium*, a pachyderm allied to *Chæropotamus* and *Hyracotherium*; also *Pæbrotherium*, an extinct ruminant allied to *Dorcatherium*, Kaup; also *Agriochœrus* of Leidy, a ruminant allied to *Merycopotamus* of Falconer and Cautley; and, lastly, a large carnivorous animal of the genus *Machairodus*, the most ancient example of which in Europe occurs in the Lower Miocene strata of Auvergne, but of which some species are found in Pliocene deposits; and one species even survived in Palæolithic times, occurring in Kent's Cavern, associated with unpolished flint implements. The turtles are referred to the genus *Testudo*, but have some affinity to *Emys*. On the whole, the Nebraska formation is probably newer than the Paris gypsum, and referable to the Lower Miocene period, as above defined.

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[1] David Dale Owen, 'Geol. Survey of Wisconsin, &c.'; Philad. 1852.

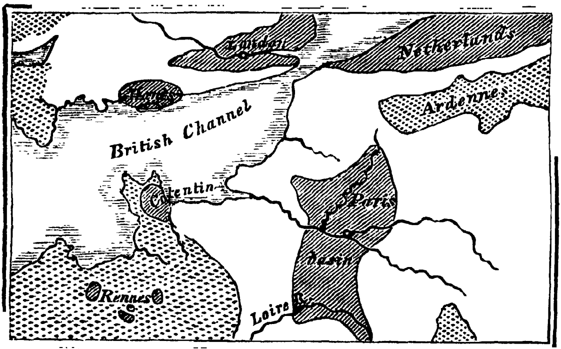
CHAPTER XVI.

EOCENE FORMATIONS.

Eocene areas of north of Europe—Table of English and French Eocene strata—Upper Eocene of England—Bembridge beds—Osborne or St. Helen's beds—Headon series—Fossils of the Barton sands and clays—Middle Eocene of England—Shells, nummulites, fish and reptiles of the Bracklesham beds and Bagshot sands—Plants of Alum Bay and Bournemouth—Lower Eocene of England—London Clay fossils—Woolwich and Reading beds formerly called 'Plastic Clay'—Fluviatile beds underlying deep-sea strata—Thanet sands—Upper Eocene strata of France—Gypseous series of Montmartre and extinct quadrupeds—Fossil footprints in Paris gypsum—Imperfection of the Record—Calcaire siliceux—Grès de Beauchamp—Calcaire grossier—Miliolite limestone—Soissonnais sands—Lower Eocene of France—Nummulitic formations of Europe, Africa, and Asia—Eocene strata in United States—Gigantic cetacean.

Eocene areas of the North of Europe.—The strata next in order in the descending series are those which I term Eocene.

Fig. 167.
Map of the principal Eocene areas of North-Western Europe.



Hypogene rocks and strata older than the Devonian

▤ Eocene formations.

N.B. The space left blank is occupied by fossiliferous formations from the Devonian to the chalk inclusive.

In the accompanying map, the position of several Eocene areas in the north of Europe is pointed out. When this map was constructed I classed as the newer part of the Eocene those Tertiary strata which have been described in the last chapter as Lower Miocene, and to which M. Beyrich has given the name of Oligocene. None of these occur in the London Basin, and they occupy in that of Hampshire, as we have seen at p. 227, too insignificant a superficial area to be noticed in a map on this scale. They fill a larger space in the Paris Basin between the Seine and the Loire, and constitute also a part of the northern limits of the area of the Netherlands which are shaded in the map.

It is in the northern part of the Isle of Wight that we have the uppermost beds of the true Eocene best exhibited, namely, those which correspond in their fossils with the celebrated gypsum of the Paris Basin before alluded to, p. 214 (see Table, p. 235). This gypsum has been selected by almost all Continental geologists as affording the best line of demarcation between the Middle and Lower Tertiary, or, in other words, between the Lower Miocene and Eocene formations.

In reference to the annexed table I may observe, that the correlation of the French and English subdivisions here laid down is often a matter of great doubt and difficulty, notwithstanding their geographical proximity. This arises from various circumstances, partly from the former prevalence of marine conditions in one basin simultaneously with fluviatile or lacustrine in the other, and sometimes from the existence of land in one area causing a break or absence of all records during a period when deposits may have been in progress in the other basin. As bearing on this subject it may be stated that we have unquestionable evidence of oscillations of level shown by the superposition of salt or brackish-water strata to fluviatile beds; and those of deep-sea origin to strata formed in shallow water. Even if the upward and downward movements were uniform in amount and direction, which is very improbable, their effect in producing the conversion of sea into land or land into sea would be different according to the previous shape and varying elevation of the land and bottom of the sea. Lastly, denudation, marine and subaërial, has frequently caused the absence of deposits in one basin of corresponding age to those in the other, and this destructive agency has been more than ordinarily effective on account of the loose and unconsolidated nature of the sands and clays.

TABLE OF ENGLISH AND FRENCH EOCENE STRATA.

English subdivisions.	French equivalents.
UPPER EOCENE.	
A. 1. Bembridge series, Isle of Wight, p. 235.	A. 1. Gypseous series of Montmartre, p. 254.
A. 2. Osborne or St. Helen's series, Isle of Wight, p. 238.	A. 2 and 3. Calcaire siliceux, or Travertin Inférieur, p. 257.
A. 3. Headon series, Isle of Wight, p. 238.	
A. 4. Barton series. Sands and clays of Barton Cliff, Hants, p. 241.	A. 4. Grès de Beauchamp, or Sables Moyens, p. 257.
MIDDLE EOCENE.	
B. 1. Bracklesham series, p. 243.	B. 1. Calcaire Grossier, p. 257.
B. 2. Alum Bay and Bournemouth beds, p. 245.	B. 2. Wanting in France ?
B. 2. Wanting in England ?	B. 2. Soissonnais Sands, or Lits Coquilliers, p. 259.
LOWER EOCENE.	
C. 1. London Clay, p. 247.	C. 1. Argile de Londres, Cassel, near Dunkirk.
C. 2. Woolwich and Reading series, p. 250.	C. 2. Argile plastique and lignite, p. 259.
C. 3. Thanet sands, p. 252.	C. 3. Sables de Bracheux, p. 260.

UPPER EOCENE, ENGLAND.

Bembridge series, A. 1.—These beds are about 120 feet thick, and, as before stated (p. 227), lie immediately under the Hempstead beds, near Yarmouth, in the Isle of Wight, being conformable with those Lower Miocene strata. They consist of marls, clays, and limestones of freshwater, brackish, and marine origin. Some of the most abundant shells, as *Cyrena semistriata* var., and *Paludina lenta* (fig. 166, p. 228), are common to this and to the overlying Hempstead series; but the majority of the species are distinct. The following are the subdivisions described by the late Professor Forbes:—

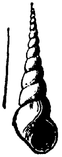
a. Upper marls, distinguished by the abundance of *Melania turritissima*, Forbes (fig. 168).

b. Lower marls, characterised by *Cerithium mutabile*, *Cyrena pulchra*, &c., and by the remains of *Trionyx* (see fig. 169).

c. Green marls, often abounding in a peculiar species of oyster, and accompanied by *Cerithium*, *Mytilus*, *Arca*, *Nucula*, &c.

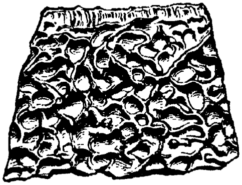
d. Bembridge limestones, compact cream-coloured limestones alternating with shales and marls, in all of which land-shells are common, especially at Sconce, near Yarmouth, as described by Mr. F. Edwards. The *Bulimus ellipticus* (fig. 170) and *Helix*

Fig. 168.



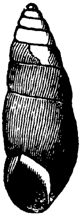
Melania turritissima, Forbes. Bembridge.

Fig. 169.



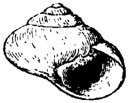
Fragment of Carapace of *Trionyx*. Bembridge Beds, Isle of Wight.

Fig. 170.



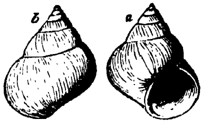
Bulimus ellipticus, Sow. Bembridge Limestone. ½ nat. size.

Fig. 171.



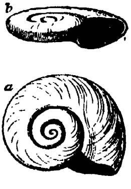
Helix occlusa, Edwards. Bembridge Limestone, Isle of Wight.

Fig. 172.



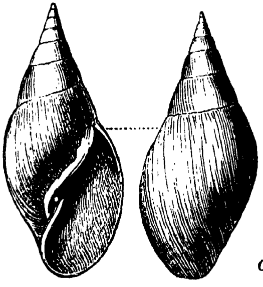
Paludina orbicularis. Bembridge.

Fig. 173.



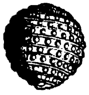
Planorbis discus, Edwards. Bembridge. ½ diam.

Fig. 174.



Limnæa fusiformis, Sow. Nat. size.

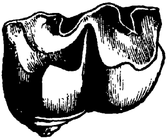
Fig. 175.



Chara tuberculata, seed-vessel. Bembridge Limestone, Isle of Wight.

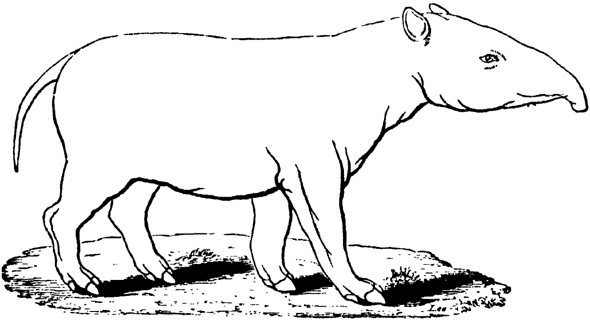
occlusa (fig. 171) are among its best known land-shells. *Paludina orbicularis* (fig. 172) is also of frequent occurrence. One of the bands is filled with a little globular *Paludina.* Among the freshwater pulmonifera, *Limnæa fusiformis,* Sow. (fig. 174) and *Planorbis discus* (fig. 173) are the most generally distributed : the latter represents or takes the place of the *Planorbis euomphalus* (see fig. 178) of the more ancient Headon series. *Chara tuberculata* (fig. 175) is the characteristic Bembridge 'gyrogonite' or seed-vessel.

Fig. 176.



Lower molar tooth, nat. size.
Anoplotherium commune.
Binstead, Isle of Wight.

Fig. 177.



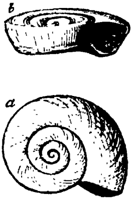
Palæotherium magnum, Cuvier.

From this formation on the shores of Whitecliff Bay, Dr. Mantell obtained a fine specimen of a fan palm, *Flabellaria Lamanonis,* Brong., a plant first obtained from beds of corresponding age in the suburbs of Paris. The well-known building-stone of Binstead, near Ryde, a limestone with numerous hollows caused by *Cyrenæ* which have disappeared and left the moulds of their shells, belongs to this subdivision of the Bembridge series. In the same Binstead stone Mr. Pratt and the Rev. Darwin Fox first discovered the remains of mammalia characteristic of the gypseous series of Paris, as *Palæotherium magnum* (fig. 177), *P. medium, P. minus, P. minimum, P. curtum, P. crassum* ; also *Anoplotherium commune* (fig. 176), *A. secundarium, Dichobune cervinum,* and *Chæropotamus Cuvieri.* The Paleothere, above alluded to, resembled the living tapir in the form of the head, and in having a short proboscis, but its molar teeth were more like those of the rhinoceros. *Palæotherium magnum* was of the size of a horse, four or five feet high. The annexed woodcut, fig. 177, is one of the restorations which Cuvier attempted of the outline of the animal when living as derived from the study of the entire skeleton. As the vertical range of particular species of quadrupeds, so far as our knowledge extends, is far more limited than that of the testacea, the occurrence of so many species at Binstead, agreeing with fossils of the Paris gypsum, strengthens the evidence derived from shells and plants of the synchronism of the two formations.

Osborne or St. Helen's series, A. 2.—This group is of fresh and brackish-water origin, and very variable in mineral character and thickness. Near Ryde, it supplies a freestone much used for building, and called by Professor Forbes the Nettlestone grit. In one part ripple-marked flag-stones occur, and rocks with fucoidal markings. The Osborne beds are distinguished by peculiar species of *Paludina*, *Melania*, and *Melanopsis*, as also of *Cypris* and the seeds of *Chara*.

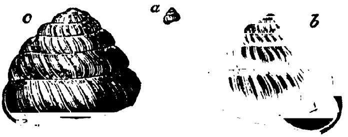
Headon series, A. 3.—These beds are seen both in Whitecliff Bay, Headon Hill, and Alum Bay, or at the east and west extremities of the Isle of Wight. The upper and lower portions are freshwater, and the middle of mixed origin, sometimes brackish and marine. Everywhere *Planorbis euomphalus* (fig. 178) characterises the freshwater deposits, just as the allied form, *P. discus* (fig. 173) does the Bembridge limestone. The brackish-water beds contain *Potamomya plana*, *Cerithium mutabile*, and *Potamides cinctus* (fig. 37, p. 32), and the marine beds *Venus* (or *Cytherea*) *incrassata*, a species common to the Limburg beds and Grès de Fontainebleau, or the Lower Miocene series. The prevalence of marine species is most conspicuous in some of the central parts of the formation.

Fig. 178.



Planorbis euomphalus, Sow. Headon Hill. ½ diam.

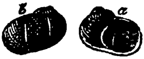
Fig. 179.



Helix labyrinthica, Say. Headon Hill, Isle of Wight; and Hordwell Cliff, Hants—also recent.

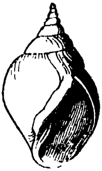
Among the shells which are widely distributed through the Headon series are *Neritina concava* (fig. 180), *Limnœa caudata* (fig. 181), and *Cerithium concavum* (fig. 182). *Helix labyrinthica*, Say (fig. 179), a land-shell now inhabiting the United States, was discovered in this series by Mr. Searles Wood in Hordwell Cliff. It is also met with in Headon Hill, in the same beds. At Sconce, in the Isle of Wight, it occurs in the Bembridge series, and affords a rare example of an Eocene fossil of a species still living, though, as usual in such cases, having no local connection with the actual geographical range of the species. The lower and middle portion of the Headon series is also met with in Hordwell Cliff (or Hordle, as it is often spelt), near Lymington, Hants. The chief shells which abound in this Cliff are *Paludina lenta* and various species of *Limnæa*, *Planorbis*, *Melania*, *Cyclas*, *Unio*, *Potamomya*, *Dreissena*, *&c.*

Fig. 180.



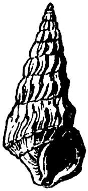
Neritina concava, Sow. Headon series.

Fig. 181.



Limnæa caudata, Edw. Headon Series.

Fig. 182.



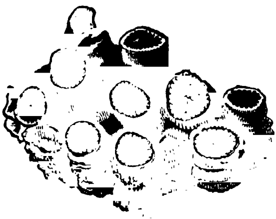
Cerithium concavum, Sow. Headon Series.

Among the chelonians we find a species of *Emys*, and no less than six species of *Trionyx*; among the saurians an alligator and a crocodile; among the ophidians two species of land-snakes (*Paleryx*, Owen); and among the fish Sir P. Egerton and Mr. Wood have found the jaws, teeth, and hard shining scales of the genus *Lepidosteus*, or bony pike of the American rivers. The same genus of freshwater ganoids has also been met with in the Hempstead beds in the Isle of Wight. The bones of several birds have been obtained from Hordwell, and the remains of quadrupeds of the genera *Palæotherium* (*P. minus*), *Anoplotherium*, *Dichodon*, *Dichobune*, *Spalacodon*, *Microchærus*, *Lophiodon*, *Hyopotamus*, and *Hyænodon*. The latter offers, I believe, the oldest known example of a true carnivorous animal in the series of British fossils; although I attach very little theoretical importance to the fact, because herbivorous species are those most easily met with in a fossil state in all save cavern deposits. In another point of view, however, this fauna deserves notice. Its geological position is considerably lower than that of the Bembridge or Montmartre beds, from which it differs almost as much in species as it does from the still more ancient fauna of the Lower Eocene beds to be mentioned in the sequel.

It therefore teaches us what a grand succession of distinct assemblages of mammalia flourished on the earth during the Eocene period.

Many of the marine shells of the brackish-water beds of the above series, both in the Isle of Wight and Hordwell Cliff, are common to the underlying Barton Clay : and on the other hand, there are some freshwater shells, such as *Cyrena obovata*, which are common to the Bembridge beds, notwithstanding the intervention of the St. Helen's series. The white and green marls of the Headon series, and some of the accompanying limestones, often resemble the Eocene strata of France in mineral character and colour in so striking a manner, as to suggest the idea that the sediment was derived from the same region or produced contemporaneously under very similar geographical circumstances.

Fig. 183.



Solenastræa cellulosa, Dunc. Brockenhurst.

At Brockenhurst, near Lyndhurst, in the New Forest, marine strata have recently been found, containing 59 species of shells, many of which have been described by Mr. Edwards. These beds rest on the Lower Headon, and are considered as the equivalent of the middle part of the Headon series, many of the shells being common to the brackish-water or Middle Headon beds of Colwell and Whitecliff Bays, such as *Cancellaria muricata*, Sow., *Fusus labiatus*, Sow., &c. In these beds at Brockenhurst, corals, ably described by Dr. Duncan, have recently been found in abundance and perfection. (See fig. 183, *Solenastræa cellulosa*).

Baron Von Könen[1] has pointed out that no less than 46 out of the 59 Brockenhurst shells, or a proportion of 78 per cent., agree with species occurring in Dumont's Lower Tongrian formation in Belgium. This being the case, we might fairly expect that if we had a marine equivalent of the Bembridge series or of the contemporaneous Paris gypsum, we should find it to contain a still greater number of shells common to the Tongrian beds of Belgium ; but the exact correlation of these freshwater groups of France, Belgium, and Britain has not yet been fully made out. It is possible that the Tongrian of Dumont may be newer than the Bembridge series, and therefore referable to the Lower Miocene. If ever the whole series should be complete, we must be prepared to find the marine equivalent of the Bembridge beds, or the uppermost Eocene, passing by imperceptible shades into the inferior beds of the overlying Miocene strata.

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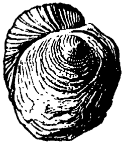
[1] Quart. Geol. Journal, vol. xx. p. 97. 1864.

Among the fossils found in the Middle Headon are *Cytherea incrassata* and *Cerithium plicatum*, fig. 163, p. 228. These shells, especially the latter, are very characteristic of the Lower Miocene, and their occurrence in the Headon series has been cited as an objection to the line proposed to be drawn between Miocene and Eocene. But if we were to attach importance to such occasional passages, we should soon find that no lines of division could be drawn anywhere, for in the present state of our knowledge of the Tertiary series there will always be species common to beds above and below our boundary-lines.

Barton series (*Sands and Clays*), A. 4, Table, p. 235.—Both in the Isle of Wight, and in Hordwell Cliff, Hants, the Headon beds, above mentioned, rest on white sands usually devoid of fossils, and used in the Isle of Wight for making glass. In one of these sands Dr. Wright found *Chama squamosa*, a Barton clay shell, in great plenty, and certain impressions of marine shells have been found in sands supposed to be of the same age in Whitecliff Bay. These sands have been called Upper Bagshot in the maps of our Government Survey, but this identification of a fossiliferous series in the Isle of Wight with an unfossiliferous formation in the London Basin can scarcely be depended upon. The Barton Clay, which immediately underlies these sands, is seen vertical in Alum Bay, Isle of Wight, and nearly horizontal in the cliffs of the mainland near Lymington. This clay, together with the Bracklesham beds, presently to be described, has been termed Middle Bagshot by the Survey. In Barton Cliff, where it attains a thickness of about 300 feet, it is rich in marine fossils.

Fig. 184.



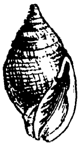
Chama squamosa, Eichw. Barton.

It was formerly confounded with the London Clay, an older Eocene deposit of very similar mineral character, to be mentioned in the sequel (p. 247), which contains many shells in common, but not more than one-fourth of the whole. In other words, there are known at present 247 species in the London Clay and 321 in that of Barton, and only 70 common to the two formations. 56 of these have been found in the intermediate Bracklesham beds, and the reappearance of the other 14 may imply a return of similar conditions, whether of temperature or depth or of a muddy argillaceous bottom, common to the two periods of the London and Barton Clays. According to M. Hebert, the most characteristic Barton Clay fossils correspond to those of the Grès de Beauchamp, or Sables Moyens, of the Paris Basin, but it also contains many common to the older Calcaire Grossier.

SHELLS OF THE BARTON CLAY.

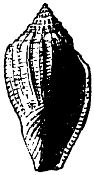
Certain foraminifera called Nummulites begin, when we study the Tertiary formations in a descending order, to make their first appearance in these beds. A small species called *Nummulites variolaria* (fig. 193) is found both on the Hampshire coast and in beds of the same age in Whitecliff Bay, in the Isle of Wight. Several marine shells, among which is *Corbula pisum* (fig. 161, p. 228), are common to the Barton beds and the

Fig. 185.



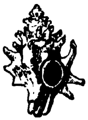
Mitra scabra, Sow.

Fig. 186.



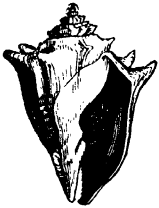
Voluta ambigua, Sol.

Fig. 187.



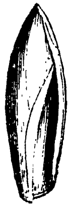
Typhis pungens, Brand.

Fig. 188.



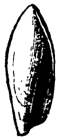
Voluta athleta, Sol. Barton, and Bracklesham.

Fig. 189.



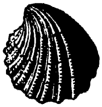
Terebellum fusiforme, Lam. Barton and Bracklesham.

Fig. 190.



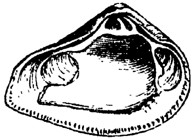
Terebellum sopita, Brand.

Fig. 191.



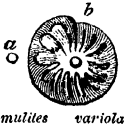
Cardita sulcata, Brand. Barton.

Fig. 192.



Crassatella sulcata, Sow. Bracklesham and Barton.

Fig. 193.



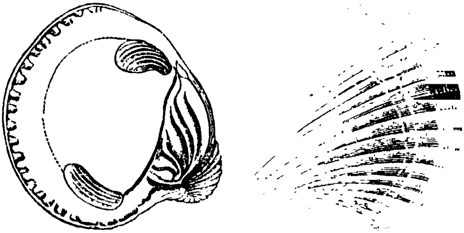
Nummulites variolaria, Lam. Var. of *N. radiata*, Sow. Mid. Eocene. Bracklesham Bay.
a. Nat. size. *b*. magnified.

Hempstead or Lower Miocene series, and a still greater number, as before stated, are common to the Headon series.

MIDDLE EOCENE, ENGLAND.

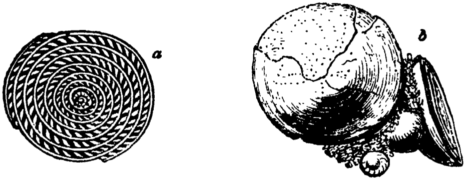
Bracklesham Beds and Bagshot Sands (B. 1, Table, p. 235)—Beneath the Barton Clay we find in the north of the Isle of Wight, both in Alum and Whitecliff Bays, a great series of various-coloured sands and clays for the most part unfossiliferous, and probably of estuarine origin. As some of these beds contain *Cardita planicosta* (fig. 194) they have been identified with the marine beds much richer in fossils seen in the coast section in Bracklesham Bay near Chichester in Sussex, where the strata consist chiefly of green clayey sands with some lignite. Among the Bracklesham fossils besides the Cardita, occurs the huge *Cerithium giganteum*, so conspicuous in the Calcaire Grossier of Paris, where it is sometimes two feet in length. *Nummulites lævigata* (see fig. 195), so characteristic of the lower beds of the Calcaire Grossier in France, where it sometimes forms stony layers, as near Compiègne, is also very common in these beds,

Fig. 194.



Cardita (Venericardia) planicosta, Lam.

Fig. 195.

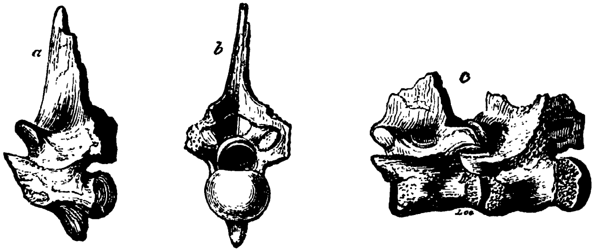


Nummulites (Nummularia) lævigata. Bracklesham. Dixon's Fossils of Sussex, Pl. 8.

a. Section of the nummulite.
b. Group, with an individual showing the exterior of the shell.

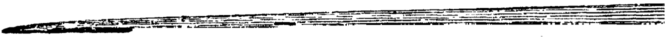
together with *N. scabra* and *N. variolaria*. Out of 193 species of testacea procured from the Bagshot and Bracklesham beds in England, 126 occur in the Calcaire Grossier in France. It was clearly, therefore, coeval with that part of the Parisian series more nearly than with any other.

Fig. 196.



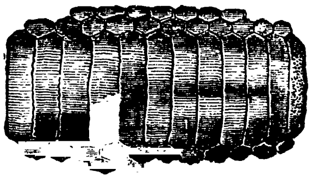
Palæophis typhæus, Owen; an Eocene sea-serpent. Bracklesham.
a, *b*. Vertebra, with long neural spine preserved.
c. Two vertebræ articulated together.

Fig. 197.



Defensive spine of Ostraceon. Bracklesham.

Fig. 198.

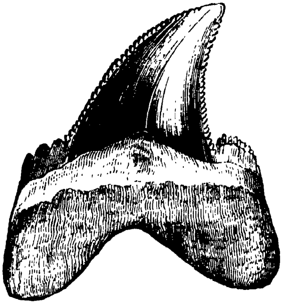


Palatal or dental plates of *Myliobates Edwardsi*. Bracklesham Bay. Dixon's Fossils of Sussex, Pl. 8.

According to tables compiled from the best authorities by Mr. Etheridge, the number of mollusca now known from the Bracklesham beds in Great Britain is 393, of which no less than 240 are peculiar to this subdivision of the British Eocene series, while 70 are common to the Older London Clay, and 140 to the Newer Barton Clay. The volutes and cowries of this formation, as well as the polyzoa and corals, favour the idea of a warm climate having prevailed, which is borne out by the discovery of the remains of a serpent, *Palæophis typhæus* (see fig. 196), exceeding, according to Professor Owen, twenty feet in length, and allied in its osteology to the Boa, Python, Coluber, and Hydrus. The compressed form and diminutive size of certain caudal vertebræ indicate so much analogy with Hydrus as to induce Professor Owen to pronounce this extinct ophidian to have been marine.[1] Amongst the companions of the sea-snake of Bracklesham was an extinct crocodile (*Gavialis Dixoni*, Owen), and numerous fish, such as now frequent the seas of warm latitudes, as the Ostraceon of the family Balistidæ, of which a dorsal spine is figured (see fig. 197),[2] and gigantic rays of the genus *Myliobates* (see fig. 198).

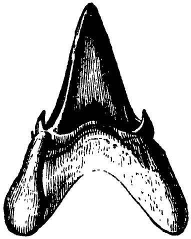
The teeth of sharks also, of the genera *Carcharodon*, *Otodus*, *Lamna*, *Galeocerdo*, and others, are abundant. (See figs. 199, 200, 201, 202).

Fig. 199.



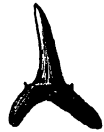
Carcharodon angustidens, Agass.

Fig. 200.



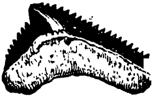
Otodus obliquus, Agass.

Fig. 201.



Lamna elegans, Agass.

Fig. 202.

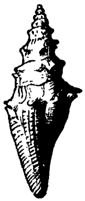


Galeocerdo latidens, Agass.

Teeth of Sharks from Bracklesham Beds.

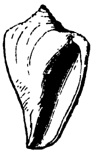
Marine Shells of Bracklesham Beds.

Fig. 203.



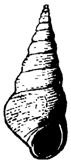
Pleurotoma attenuata, Sow.

Fig. 204.



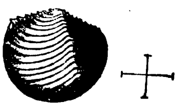
Voluta Selseiensis, Edwards.

Fig. 205.



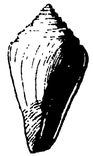
Turritella multisulcata, Lam.

Fig. 206.



Lucina serrata, Sow. Magnified.

Fig. 207.



Conus deperditus, Brug.

Alum Bay and Bournemouth beds (*Lower Bagshot of English Survey*), B. 2, Table, p. 235.—To that great series of sands and clays which intervene between the equivalents of the Bracklesham Beds and the London Clay or Lower Eocene, our Government Survey has given the name of the Lower Bagshot sands, for they are supposed to agree in age with the inferior unfossiliferous sands of the country round Bagshot in the London Basin. This part of the series is finely exposed in the vertical beds of Alum Bay in the Isle of Wight, and east and west of Bournemouth on the south coast of Hampshire. In some of the close and white compact clays of this locality, there are not only dicotyledonous leaves, but numerous fronds of ferns allied to Gleichenia which are well preserved with their fruit.

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[1] Paleont. Soc. Monograph. Rept., pt. ii. p. 61.

[2] For a description of this spine see W. C. Williamson, Phil. Trans. pt. ii., 1851, p. 667.

None of the beds are of great horizontal extent, and there is much cross-stratification or false-bedding in the sands, and in some places black carbonaceous seams and lignite. In the midst of a leaf-bed at the base of the Bournemouth strata in Studland Bay, Dorsetshire, shells of the genus Unio attest the freshwater origin of the white clay.

No less than 40 species of plants are mentioned by MM. de la Harpe and Gaudin from this formation in Hampshire, among which the Proteaceæ (*Dryandra*, &c.) and the fig tribe are abundant, as well as the cinnamon and several other laurineæ, with some papilionaceous plants. On the whole they remind the botanist of the types of subtropical India and Australia.[1]

Heer has mentioned several species which are common to this Alum Bay flora and that of Monte Bolca, near Verona, so celebrated for its fossil fish, and where the strata contain nummulites and other Middle Eocene fossils. He has particularly alluded to *Aralia primigenia* (of which genus a fruit has since been found by Mr. Mitchell at Bournemouth), *Daphnogene Veronensis*, and *Ficus granadilla*, as among the species common to and characteristic of the Isle of Wight and Italian Eocene beds; and he observes that in the flora of this period those forms of a temperate climate which constitute a marked feature in the European Miocene formations, such as the willow, poplar, birch, alder, elm, hornbeam, oak, fir, and pine, are wanting. The American types are also absent, or much more feebly represented than in the Miocene period, although fine specimens of the fan-palm (*Sabal*) have been found in these Eocene clays at Studland. The number of exotic forms which are common to the Eocene and Miocene strata of Europe, like those to be alluded to in the sequel which are common to the Eocene and Cretaceous fauna, demonstrate the remoteness of the times in which the geographical distribution of living plants originated. A great majority of the Eocene genera have disappeared from our temperate climates, but not the whole of them; and they must all have exerted some influence on the assemblages of species which succeeded them. Many of these last occurring in the Upper Miocene are indeed so closely allied to the flora now surviving as to make it questionable, even in the opinion of naturalists opposed to the doctrine of transmutation, whether they are not genealogically related the one to the other.

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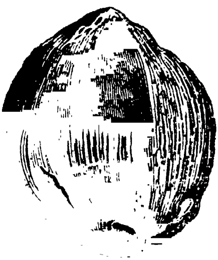
[1] Heer, 'Climat et Végétation du Pays Tertiaire,' p. 172.

LOWER EOCENE FORMATIONS, ENGLAND.

London Clay (C. 1, Table, p. 235).—This formation underlies the preceding, and sometimes attains a thickness of 500 feet. It consists of tenaceous brown and bluish-gray clay, with layers of concretions called septaria, which abound chiefly in the brown clay, and are obtained in sufficient numbers from sea-cliffs near Harwich, and from shoals off the coast of Essex and the Isle of Sheppey, to be used for making Roman cement. The total number of British fossil mollusca known at present (January 1870) in this formation are 266, of which 160 are peculiar, or not found in other Eocene beds in this country. The principal localities of fossils in the London clay are Highgate Hill, near London, the island of Sheppey at the mouth of the Thames, and Bognor on the Sussex coast. Out of 133 fossil shells, Mr. Prestwich found only 20 to be common to the Calcaire Grossier (from which 600 species have been obtained), while 33 are common to the 'Lits Coquilliers' (p. 259), in which 200 species are known in France.

In the Island of Sheppey near the mouth of the Thames the thickness of the London Clay is estimated by Mr. Prestwich to be more than 500 feet; and it is in the uppermost 50 feet that a great number of fossil fruits were obtained, being chiefly found on the beach when the sea has washed away the clay of the rapidly wasting cliffs.

Fig. 208.

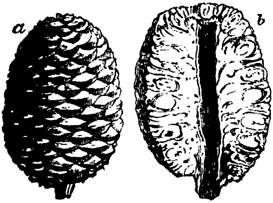


Nipadites ellipticus, Bow. Fossil fruit of palm, from Sheppey.

Mr. Bowerbank, in a valuable publication on these fossil fruits and seeds, has described no less than thirteen fruits of palms of the recent type *Nipa*, now only found in the Molucca and Philippine Islands, and in Bengal (see fig. 208). In the delta of the Ganges, Dr. Hooker observed the large nuts of *Nipa fruticans* floating in such numbers in the various arms of that great river, as to obstruct the paddle-wheels of steam-boats. These plants are allied to the cocoa-nut tribe on the one side, and on the other to the *Pandanus*, or screwpine. There are also met with three species of *Anona*, or custard apple; and cucurbitaceous fruits (of the gourd and melon family), and fruits of various species of *Acacia*.

Besides fir-cones or fruit of true Coniferæ there are cones of Proteaceæ in abundance, and the celebrated botanist the late Robert Brown pointed out the affinity of these to the New Holland types *Petrophila* and *Isopogon*. Of the first there are about 50 and the second 30 described species now living in Australia.

Fig. 209.



Eocene Proteaceous Fruit.

Petrophiloides Richardsoni, London Clay, Sheppey. Natural size.
a. Cone. *b*. Section of cone showing the position of the seeds.

Ettingshausen remarked in 1851 that five of the fossil species from Sheppey, named by Bowerbank,[1] were specimens of the same fruit (see fig. 209) in different states of preservation; and Mr. Carruthers, having examined the original specimens now in the British Museum, tells me that all these cones from Sheppey may be reduced to two species, which have an undoubted affinity to the two existing Australian genera above mentioned, although their perfect identity in structure cannot be made out.

The contiguity of land may be inferred not only from these vegetable productions, but also from the teeth and bones of crocodiles and turtles, since these creatures, as Dean Conybeare remarked, must have resorted to some shore to lay their eggs. Of turtles there were numerous species referred to extinct genera. These are, for the most part, not equal in size to the largest living tropical turtles. A sea-snake, which must have been thirteen feet long, of the genus *Palæophis* before mentioned (p. 244), has also been described by Professor Owen from Sheppey, of a different species from that of Bracklesham, and called *P. toliapicus*. A true crocodile, also, *Crocodilus toliapicus*, and another saurian more nearly allied to the gavial, accompany the above fossils; also the relics of several birds and quadrupeds. One of these last belongs to the new genus *Hyracotherium* of Owen, of the hog tribe, allied to Chæropotamus; another is a *Lophiodon*; a third a pachyderm called *Coryphodon eocænus* by Owen, larger than any existing tapir. All these animals seem to have inhabited the banks of the great river which floated down the Sheppey fruits. They imply the existence of a mammiferous fauna antecedent to the period when nummulites flourished in Europe and Asia, and therefore before the Alps, Pyrenees, and other mountain-chains now forming the back-bones of great continents, were raised from the deep ; nay, even before a part of the constituent rocky masses now entering into the central ridges of these chains had been deposited in the sea.

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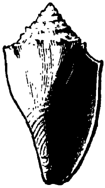
[1] Bowerbank, 'Fossil Fruits and Seeds of London Clay,' Plates ix. and x.

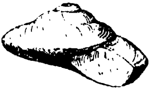
SHELLS OF THE LONDON CLAY.

Fig. 210.



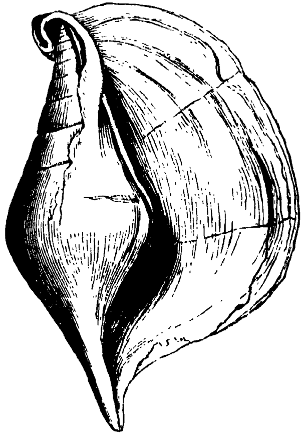
Voluta nodosa, Sow. Highgate.

Fig. 211.



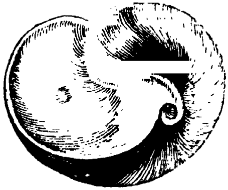
Phorus extensus, Sow. Highgate.

Fig. 212.



Rostellaria (*Hippocrenes*) *ampla*. Brander. ⅓ of nat. size ; also found in the Barton clay.

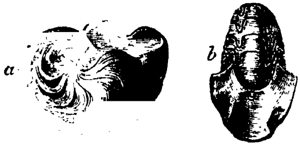
Fig. 213.



Nautilus centralis, Sow. Highgate.

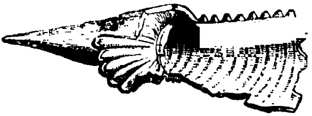
The marine shells of the London clay confirm the inference derivable from the plants and reptiles in favour of a high temperature. Thus many species of *Conus* and *Voluta* occur, a large *Cypræa*, *C. oviformis*, a very large *Rostellaria* (fig. 212), a species of *Cancellaria*, six species of *Nautilus* (fig. 214), besides other Cephalopoda of extinct genera, one of the most remarkable of

Fig. 214.



Aturia ziczac, Bronn. Syn. *Nautilus ziczac*, Sow. London clay. Sheppey.

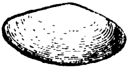
Fig. 215.



Belosepia sepioidea, De Blainv. London clay. Sheppey.

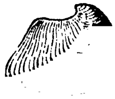
which is the *Belosepia* (fig. 215). Among many characteristic bivalve shells are *Leda amygdaloides* (fig. 216) and *Cryptodon angulatum* (fig. 217), and among the Radiata a star-fish, *Astropecten* (fig. 218).

Fig. 216.



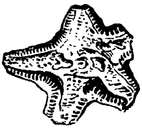
Leda amygdaloides, Sow. Highgate.

Fig. 217.



Cryptodon (Axinus) angulatum, Sow. London clay, Hornsey.

Fig. 218.



Astropecten crispatus, E. Forbes. Sheppey.

These fossils are accompanied by a sword-fish (*Tetrapterus priscus*, Agassiz), about eight feet long, and a saw-fish (*Pristis bisulcatus, Ag.*), about ten feet in length ; genera now foreign to the British seas. On the whole, about eighty species of fish have been described by M. Agassiz from these beds of Sheppey, and they indicate, in his opinion, a warm climate.

In the lower part of the London clay at Kyson, a few miles east of Woodbridge, the remains of mammalia have been detected. Some of these have been referred by Professor Owen to an opossum, and others to the genus *Hyracotherium*. The teeth of this last-mentioned Pachyderm were at first, in 1840, supposed to belong to a monkey ; an opinion afterwards abandoned by Owen when more ample materials for comparison were obtained.

Woolwich and Reading series (C. 2, Table, p. 235).—This formation was formerly called the Plastic Clay, as it agrees with a similar clay used in pottery which occupies the same position in the French series, and it has been used for the like purposes in England.[1]

No formations can be more dissimilar on the whole in mineral character than the Eocene deposits of England and Paris ; those of our own island being almost exclusively of mechanical origin, —accumulations of mud, sand, and pebbles ; while in the neighbourhood of Paris we find a great succession of strata composed of limestones, some of them siliceous, and of crystalline gypsum and siliceous sandstone, and sometimes of pure flint used for millstones. Hence it is often impossible, as before stated, to institute an exact comparison between the various members of the English and French series, and to settle their respective ages. But in regard to the division which we have now under consideration, whether we study it in the basins of London, Hampshire, or Paris, we recognise as a general rule the same mineral character, the beds consisting over a large area of mottled clays and sand, with lignite, and with some strata of well-rolled flint pebbles, derived from the chalk, varying in size, but occasionally several inches in diameter. These strata may be seen in the Isle of Wight or at Bognor in contact with the chalk, or in the London Basin, at Reading, Blackheath, and Woolwich. In some of the lowest of them, banks of oysters are observed, consisting of *Ostrea bellovacina,* so common in France in the same relative position. In these beds at Bromley, Dr. Buckland found a large pebble to which five full-grown oysters were affixed, in such a manner as to show that they had commenced their first growth upon it, and remained attached through life.

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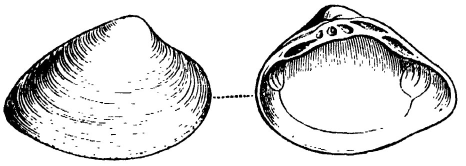
[1] Prestwich, Quart. Geol. Journ. vol. x.

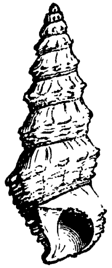
In several places, as at Woolwich on the Thames, at Newhaven in Sussex, and elsewhere, a mixture of marine and freshwater testacea distinguishes this member of the series. Among the latter, *Melania inquinata* (see fig. 220) and *Cyrena Cuneiformis* (see fig. 219) are very common, as in beds of corresponding age in France. They clearly indicate points where rivers entered the Eocene sea. Usually there is a mixture of brackish, freshwater, and marine shells, and sometimes, as at Woolwich, proofs of the river and the sea having successively prevailed on the same spot. At New Charlton, in the suburbs of Woolwich, Mr. de la Condamine discovered in 1849, and pointed out to me, a layer of sand associated with well-rounded flint pebbles in which numerous individuals of the *Cyrena tellinella* were seen standing endwise with both their valves united, the siphonal extremity of each shell being uppermost, as would happen if the mollusks had died in their natural position. I have described[1] a bank of

Fig. 219.



Cyrena cuneiformis, Sow. Natural size.
Woolwich clays.

Fig. 220.



Melania (*Melanatria*) *inquinata*, Def. Syn.
Cerithium melanoides,
Sow. Woolwich clays.

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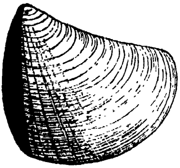
[1] Second Visit to the United States, vol. ii. p. 104.

sandy mud, in the delta of the Alabama River at Mobile, on the borders of the Gulf of Mexico, where in 1846 I dug out at low tide specimens of living species of *Cyrena* and of a *Gnathodon*, which were similarly placed with their shells erect, or in a posture which enables the animal to protrude its siphon upwards and draw in or reject water at pleasure. The water at Mobile is usually fresh, but sometimes brackish. At Woolwich a body of river-water must have flowed permanently into the sea where the *Cyrenæ* lived, and they may have been killed suddenly by an influx of pure salt water, which invaded the spot when the river was low, or when a subsidence of land took place. Traced in one direction, or eastward towards Herne Bay, the Woolwich beds assume more and more of a marine character; while in an opposite, or south-western direction, they become, as near Chelsea and other places, more freshwater, and contain *Unio*, *Paludina*, *Pitharella*, and layers of lignite, so that the land drained by the ancient river seems clearly to have been to the south-west of the present site of the metropolis.

Fluviatile beds underlying deep-sea strata.—Before the minds of geologists had become familiar with the theory of the gradual sinking of land, and its conversion into sea at different periods, and the consequent change from shallow to deep water, the fluviatile and littoral character of this inferior group appeared strange and anomalous. After passing through hundreds of feet of London clay, proved by its fossils to have been deposited in salt water, we arrive at beds of fluviatile origin, and associated with them masses of shingle, attaining at Blackheath, near London, a thickness of 50 feet. These shingle banks are probably of marine origin, but they indicate the proximity of land, and the existence of a shore where the flints of the chalk were rolled into sand and pebbles, and spread over a wide space. We have, therefore, first, as before stated (p. 251), evidence of oscillations of level during the accumulation of the Woolwich series, then of a great submergence, which allowed a marine deposit 500 feet thick to be laid over the antecedent beds of fresh and brackish-water origin.

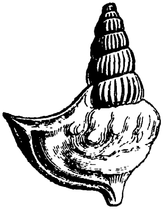
Thanet sands (C. 3, Table, p. 235).—The Woolwich or plastic clay above described may often be seen in the Hampshire Basin in actual contact with the chalk, constituting in such places the lowest member of the British Eocene series. But at other points another formation of marine origin, characterised by a somewhat different assemblage of organic remains, has been shown by Mr. Prestwich to intervene between the chalk and the Woolwich series. For these beds he has proposed the name of 'Thanet Sands,' because they are well seen in the Isle of Thanet, in the northern part of Kent, and on the sea-coast between Herne Bay and the Reculvers, where they consist of sands with a few concretionary masses of sandstone, and contain, among other fossils, *Pholadomya cuneata* (fig. 221), *Cyprina Morrisi* (fig. 222), *Corbula longirostris*, *Scalaria Bowerbankii*, *Aporrhais Sowerbyi* (fig. 223), &c. The greatest thickness of these beds is about 90 feet.

Fig. 221.



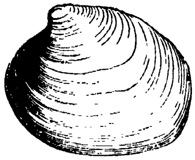
Pholadomya cuneata, Sow.
Thanet sands.

Fig. 222.



Aporrhais Sowerbyi, Mant.
Thanet sands.

Fig. 223.



Cyprina Morrisii, Sow.
Thanet sands.

UPPER EOCENE FORMATIONS OF FRANCE.

The Tertiary formations in the neighbourhood of Paris consist of a series of marine and freshwater strata, alternating with each other, and filling up a depression in the chalk. The area which they occupy has been called the Paris Basin, and is about 180 miles in its greatest length from north to south, and about 90 miles in breadth from east to west. MM. Cuvier and Brongniart attempted, in 1810, to distinguish five different groups, comprising three freshwater and two marine, which were supposed to imply that the waters of the ocean, and of rivers and lakes, had been by turns admitted into and excluded from the same area. Investigations since made in the Hampshire and London Basins have rather tended to confirm these views, at least so far as to show that since the commencement of the Eocene period there have been great movements of the bed of the sea, and of the adjoining lands, and that the superposition of deep sea to shallow water deposits (the London clay, for example, to the Woolwich beds) can only be explained by referring to such movements. It appears, notwithstanding, from the researches of M. Constant Prévost, that some of the minor alternations and intermixtures of freshwater and marine deposits, in the Paris Basin, may be accounted for without such changes of level, by imagining both to have been simultaneously in progress, in the same bay of the same sea, or a gulf into which many rivers entered.

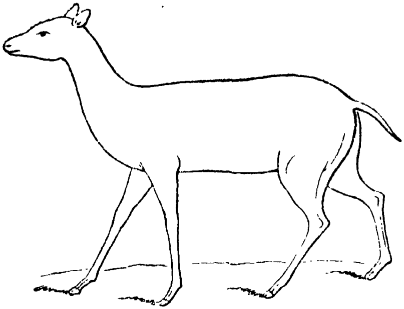
Gypseous series of Montmartre (A. 1, Table, p. 235).—To enlarge on the numerous subdivisions of the Parisian strata would lead me beyond my present limits ; I shall therefore give some examples only of the most important formations. Beneath the Grès de Fontainebleau, belonging, as before stated, to the Lower Miocene period, we find, in the neighbourhood of Paris, a series of white and green marls, with subordinate beds of gypsum. These are most largely developed in the central parts of the Paris Basin, and, among other places, in the hill of Montmartre, where its fossils were first studied by Cuvier.

The gypsum quarried there for the manufacture of plaster of Paris occurs as a granular crystalline rock, and, together with the associated marls, contains land and fluviatile shells, and the bones and skeletons of birds and quadrupeds. Several land-plants are also met with, among which are fine specimens of the fan-palm or palmetto tribe (*Flabellaria*). The remains also of freshwater fish, and of crocodiles and other reptiles, occur in the gypsum. The skeletons of mammalia are usually isolated, often entire, the most delicate extremities being preserved ; as if the carcases, clothed with their flesh and skin, had been floated down soon after death, and while they were still swollen by the gases generated by their first decomposition. The few accompanying shells are of those light kinds which frequently float on the surface of rivers, together with wood.

In this formation the relics of about fifty species of quadrupeds, including the genera *Palæotherium* (see fig. 177, p. 237), *Anoplotherium*, and others, have been found, all extinct, and nearly four-fifths of them belonging to the Perissodactyle or odd-toed division of the order *Pachydermata*, which now contains only four living genera, namely, rhinoceros, tapir, horse, and hyrax. The *Anoplotheridæ* form a tribe intermediate between pachyderms and ruminants. One of the three divisions of this family was called by Cuvier *Xiphodon*. Their forms were slender and elegant, and one, named *Xiphodon gracile* (fig. 224), was about the size of the chamois ; and Cuvier inferred from the skeleton that it was as light, graceful, and agile as the gazelle. With these Pachydermata are associated a few carnivorous animals, among which are the *Hyænodon dasyuroides* ; a species of dog, *Canis Parisiensis* ; and a weasel, *Cynodon Parisiensis*. Of the *Rodentia* are found a squirrel ; of the *Cheiroptera*, a bat ; while the *Marsupialia* (an order now confined to America, Australia, and some contiguous islands) are represented by an opossum.

Of birds, about 17 species has been discovered, five of which are still undetermined. The skeletons of some are entire, but none are referable to existing species.[1] The same remark, according to MM. Cuvier and Agassiz, applies both to the reptiles and fish. Among the last are crocodiles and tortoises of the genera *Emys* and *Trionyx*. The tribe of land quadrupeds most abundant in this formation is such as now inhabits alluvial plains and marshes, and the banks of rivers and lakes, a class most exposed to suffer by river inundations.

Fig. 224.



Xiphodon gracile, or *Anoplotherium gracile*, Cuvier. Restored outline.

Fossil footprints.—There are three superimposed masses of gypsum in the neighbourhood of Paris, separated by intervening deposits of laminated marl. In the uppermost of the three in the valley of Montmorency M. Desnoyers discovered in 1859 many footprints of animals occurring at no less than six different levels.[2] The gypsum to which they belong varies from thirty to fifty feet in thickness, and is that which has yielded to the naturalist the largest number of bones and skeletons of mammalia, birds, and reptiles. I visited the quarries, soon after the discovery was made known, with M. Desnoyers, who also showed me large slabs in the Museum at Paris, where, on the upper planes of stratification, the indented footmarks were seen, while corresponding casts in relief appeared on the lower surfaces of the strata of gypsum which were immediately superimposed. A thin film of marl, which before it was dried and condensed by pressure must have represented a much thicker layer of soft mud, intervened between the beds of solid gypsum. On this mud the animals had trodden, and made impressions which had penetrated to the gypseous mass below, then evidently unconsolidated. Tracks of the *Anoplotherium* with its bisulcate hoof, and the trilobed footprints of *Palæotherium*, were seen of different sizes, corresponding to those of several species of these genera which Cuvier had reconstructed, while in the same beds were footmarks of carnivorous mammalia. The tracks also of fluviatile, lacustrine, and terrestrial tortoises (*Emys*, *Trionyx*, &c.) were discovered; also those of crocodiles, iguanas, geckos, and great batrachians; and the footprints of a huge bird, apparently a wader, of the size of the gastornis, to be mentioned in the sequel. There were likewise impressions of the feet of other creatures, some of them clearly distinguishable from any of the fifty extinct types of mammalia, of which the bones have been found in the Paris gypsum. The whole assemblage, says Desnoyers, indicates the shores of a lake, or several small lakes communicating with each other, on the borders of which many species of Pachyderms wandered, and beasts of prey which occasionally devoured them. The tooth-marks of these last had been detected by palæontologists long before on the bones and skulls of *Paleotheres* entombed in the gypsum.

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[1] Cuvier, Oss. Foss., tom. iii. p. 255.

[2] Sur des Empreintes de Pas d'Animaux, par M. J. Desnoyers. Compte rendu de l'Institut, 1859.

Imperfection of the Record.—These footmarks have revealed to us new and unexpected proofs that the air-breathing fauna of the Upper Eocene period in Europe far surpassed in the number and variety of its species the largest estimate which had previously been formed of it. We may now feel sure that the mammalia, reptiles, and birds, which have left portions of their skeletons as memorials of their existence in the solid gypsum, constituted but a part of the then living creation. Similar inferences may be drawn from the study of the whole succession of geological records. In each district the monuments of periods embracing thousands, and probably in some instances hundreds of thousands of years, are totally wanting. Even in the volumes which are extant the greater number of the pages are missing in any given region, and where they are found they contain but few and casual entries of the physical events or living beings of the times to which they relate. It may also be remarked that the subordinate formations met with in two neighbouring countries, such as France and England, commonly classed as equivalents and referred to corresponding periods, may nevertheless have been by no means strictly coincident in date. Though called contemporaneous, it is probable that they were often separated by intervals of many thousands of years. We may compare them to double stars, such as the polar star, which appear single to the naked eye because seen from a vast distance in space, and which really belong to one and the same stellar system, though occupying places in space extremely remote if estimated by our ordinary standard of terrestrial measurements.

Calcaire siliceux, or Travertin inférieur (A. 2 and 3, Table, p. 235).—This compact siliceous limestone extends over a wide area. It resembles a precipitate from the waters of mineral springs, and is often traversed by small empty sinuous cavities. It is, for the most part, devoid of organic remains, but in some places contains freshwater and land species, and never any marine fossils. The calcaire siliceux and the calcaire grossier usually occupy distinct parts of the Paris Basin, the one attaining its fullest development in those places where the other is of slight thickness. They are described by some writers as alternating with each other towards the centre of the basin, as at Sergy and Osny.

The gypsum, with its associated marls before described, is in greatest force towards the centre of the basin, where the calcaire grossier and calcaire siliceux are less fully developed.

Grès de Beauchamp or Sables Moyens (A. 4, Table, p. 235).—In some parts of the Paris Basin, sands and marls, called the Grès de Beauchamp, or Sables moyens, divide the gypseous beds from the calcaire grossier proper. These sands, in which a small nummulite (*N. variolaria*) is very abundant, contain more than 300 species of marine shells, many of them peculiar, but others common to the next division.

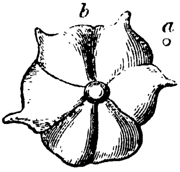
MIDDLE EOCENE FORMATIONS OF FRANCE.

Calcaire Grossier, upper and middle (B. 1, Table, p. 235).—The upper division of this group consists in great part of beds of compact, fragile limestone, with some intercalated green marls. The shells in some parts are a mixture of *Cerithium*, *Cyclostoma*, and *Corbula*; in others *Limnæa*, *Cerithium*, *Paludina*, &c. In the latter, the bones of reptiles and mammalia, *Palæotherium* and *Lophiodon*, have been found. The middle division, or calcaire grossier proper, consists of a coarse limestone, often passing into sand. It contains the greater number of the fossil shells which characterise the Paris Basin. No less than 400 distinct species have been procured from a single spot near Grignon, where they are embedded in a calcareous sand, chiefly formed of comminuted shells, in which, nevertheless, individuals in a perfect state of preservation, both of marine, terrestrial, and freshwater species, are mingled together. Some of the marine shells may have lived on the spot; but the *Cyclostoma* and *Limnæa* being land and freshwater shells, must have been brought thither by rivers and currents, and the quantity of triturated shells implies considerable movement in the waters.

Nothing is more striking in this assemblage of fossil testacea than the great proportion of species referable to the genus *Cerithium* (see figures, p. 228). There occur no less than 137 species of this genus in the Paris Basin, and almost all of them in the calcaire grossier. Most of the living *Cerithia* inhabit the sea near the mouths of rivers, where the waters are brackish; so that their abundance in the marine strata now under consideration is in harmony with the hypothesis that the Paris Basin formed a gulf into which several rivers flowed.

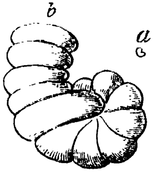
EOCENE FORAMINIFERA.

Fig. 225.



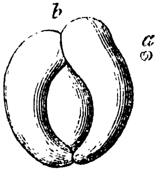
Calcarina rarispina, Desh.

Fig. 226.



Spirolina stenostoma, Desh.

Fig. 227.



Triloculina inflata, Desh.

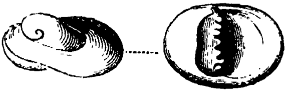
a. Natural size. *b*. Magnified.

In some parts of the calcaire grossier round Paris, certain beds occur of a stone used in building, and called by the French geologists 'Miliolite limestone.' It is almost entirely made up of millions of microscopic shells, of the size of minute grains of sand, which all belong to the class Foraminifera. Figures of some of these are given in the annexed woodcut. As this miliolitic stone never occurs in the Faluns, or Upper Miocene strata of Brittany and Touraine, it often furnishes the geologist with a useful criterion for distinguishing the detached Eocene and Upper Miocene formations scattered over those and other adjoining provinces. The discovery of the remains of Palæotherium and other mammalia in some of the upper beds of the calcaire grossier shows that these land animals began to exist before the deposition of the overlying gypseous series had commenced.

Lower Calcaire grossier, or Glauconie grossière (B. 1, Table, p. 235).—The lower part of the calcaire grossier, which often contains much green earth, is characterised at Auvers, near Pontoise, to the north of Paris, and still more in the environs of Compiègne, by the abundance of nummulites, consisting chiefly of *N. lævigata*, *N. scabra*, and *N. Lamarcki*, which constitute a large proportion of some of the stony strata, though these same foraminifera are wanting in beds of similar age in the immediate environs of Paris.

Soissonnais sands, or Lits coquilliers (B. 2, Table, p. 235). —Below the preceding formation shelly sands are seen, of considerable thickness, especially at Cuisse-Lamotte, near Compiègne, and other localities in the Soissonnais, about fifty miles N.E. of Paris, from which about 300 species of shells have been obtained, many of them common to the calcaire grossier and the Bracklesham beds of England, and many peculiar. The *Nummulites planulata* is very abundant, and the most characteristic shell is the *Nerita conoidea*, Lam., a fossil which has a very wide geographical range; for, as M. d'Archiac remarks, it accompanies the nummulitic formation from Europe to India, having been found in Cutch, near the mouths of the Indus, associated with *Nummulites scabra.* No less than 33 shells of this group are said to be identical with shells of the London clay proper; yet, after visiting Cuisse-Lamotte and other localities of the 'Sables inférieurs' of D'Archiac, I agree with Mr. Prestwich that the latter are probably newer than the London clay, and perhaps older than the Bracklesham beds of England. The London clay seems to be unrepresented in the Paris Basin, unless partially so, by these sands.[1]

Fig. 228.



Nerita conoidea, Lam.
Syn. N. *Schmidelliana*, Chemnitz.

LOWER EOCENE FORMATIONS OF FRANCE.

Argile plastique (C. 2, Table, p. 235).—At the base of the Tertiary system in France are extensive deposits of sands, with occasional beds of clay used for pottery, and called 'argile plastique.' Fossil oysters (*Ostrea bellovacina*) abound in some places; and in others there is a mixture of fluviatile shells, such as *Cyrena cuneiformis* (fig. 219, p. 251), *Melania inquinata* (fig. 220), and others, frequently met with in beds occupying the same position in the London Basin. Layers of lignite also accompany the inferior clays and sands.

Immediately upon the chalk at the bottom of all the tertiary strata in France there generally is a conglomerate or breccia of rolled and angular chalk-flints, cemented by siliceous sand. These beds appear to be of littoral origin, and imply the previous emergence of the chalk, and its waste by denudation. In the year 1855, the tibia and femur of a large bird, equalling at least the ostrich in size, were found at Meudon, near Paris, at the base of the Plastic clay. This bird, to which the name of *Gastornis Parisiensis* has been assigned, appears, from the Memoirs of MM. Hébert, Lartet, and Owen, to belong to an extinct genus. Professor Owen refers it to the class of wading land birds rather than to an aquatic species.[1]

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[1] D'Archiac, Bulletin, tom. x.; and Prestwich, Geol. Quart. Journ., 1847, p. 377.

That a formation so much explored for economical purposes as the Argile plastique around Paris, and the clays and sands of corresponding age near London, should never have afforded any vestige of a feathered biped previously to the year 1855, shows what diligent search and what skill in osteological interpretation are required before the existence of birds of remote ages can be established.

Sables de Bracheux (C. 3, Table, p. 235).—The marine sands called the Sables de Bracheux (a place near Beauvais) are considered by M. Hébert to be older than the Lignites and Plastic clay, and to coincide in age with the Thanet Sands of England. At La Fère, in the Department of Aisne, in a deposit of this age, a fossil skull has been found of a quadruped called by Blainville *Arctocyon primævus*, and supposed by him to be related both to the bear and to the Kinkajou (*Cercoleptes*). This creature appears to be the oldest known tertiary mammifer.

Nummulitic formation of Europe, Asia, &c.—Of all the rocks of the Eocene period, no formations are of such great geographical importance as the Upper and Middle Eocene, as above defined, assuming that the older tertiary formation, commonly called nummulitic, is correctly ascribed to this group. It appears that of more than fifty species of these foraminifera described by D'Archiac, one or two species only are found in other tertiary formations whether of older or newer date. *Nummulites intermedia*, a Middle Eocene form, ascends into the Lower Miocene, but it seems doubtful whether any species descends to the level of the London clay, still less to the Argile plastique or Woolwich beds. Separate groups of strata are often characterised by distinct species of nummulite; thus the beds between the Lower Miocene and the Lower Eocene may be divided into three sections, distinguished by three different species of nummulites—*N. variolaria* in the upper, *N. lævigata* in the middle, and *N. planulata* in the lower beds. The nummulitic limestone of the Swiss Alps rises to more than 10,000 feet above the level of the sea, and attains here and in other mountain-chains a thickness of several thousand feet. It may be said to play a far more conspicuous part than any other tertiary group in the solid framework of the earth's crust, whether in Europe, Asia, or Africa. It occurs in Algeria and Morocco, and has been traced from Egypt, where it was largely quarried of old for the building of the Pyramids, into Asia Minor, and across Persia by Bagdad to the mouths of the Indus. It has been observed not only in Cutch, but in the mountain-ranges which separate Scinde from Persia, and which form the passes leading to Caboul; and it has been followed still farther eastward into India, as far as Eastern Bengal and the frontiers of China.

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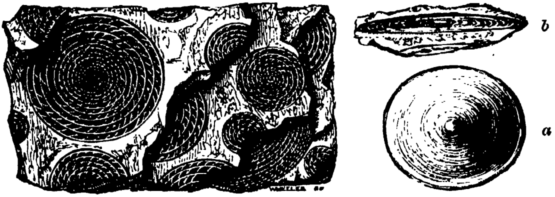
[1] Quart. Geol. Journ., vol. xii. p. 204. 1856.

Dr. T. Thomson found nummulites in Western Thibet at an elevation of no less than 16,500 feet above the level of the sea. One of the species, which I myself found very abundant on the flanks of the Pyrenees, in a compact crystalline marble (fig. 229), is called by M. d'Archiac *Nummulites Puschi*. The same is also very common in rocks of the same age in the Carpathians. In many distant countries, in Cutch, for example, some of the same shells, such as *Nerita conoidea* (fig. 228), accompany the nummulites, as in France. The opinion of many observers, that the Nummulitic formation belongs partly to the cretaceous era, seems chiefly to have arisen from confounding an allied genus, Orbitoides, with the true Nummulite.

Fig. 229.



Nummulites Puschi, D'Archiac. Peyrehorade, Pyrenees.
a. External surface of one of the nummulites, of which longitudinal sections are seen in the limestone. *b.* Transverse section of same.

When we have once arrived at the conviction that the nummulitic formation occupies a middle and upper place in the Eocene series, we are struck with the comparatively modern date to which some of the greatest revolutions in the physical geography of Europe, Asia, and Northern Africa must be referred. All the mountain-chains, such as the Alps, Pyrenees, Carpathians, and Himalayas, into the composition of whose central and loftiest parts the nummulitic strata enter bodily, could have had no existence till after the Middle Eocene period. During that period the sea prevailed where these chains now rise, for nummulites and their accompanying testacea were unquestionably inhabitants of salt water. Before these events, comprising the conversion of a wide area from a sea to a continent, England had been peopled, as I before pointed out (p. 248), by various quadrupeds, by herbivorous pachyderms, by insectivorous bats, and by opossums.

Almost all the volcanoes which preserve any remains of their original form, or from the craters of which lava streams can be traced, are more modern than the Eocene fauna now under consideration; and besides these superficial monuments of the action of heat, Plutonic influences have worked vast changes in the texture of rocks within the same period. Some members of the nummulitic and overlying tertiary strata called *flysch* have actually been converted in the central Alps into crystalline rocks, and transformed into marble, quartz-rock, mica-schist, and gneiss.[1]

Eocene strata in the United States.—In North America the Eocene formations occupy a large area bordering the Atlantic, which increases in breadth and importance as it is traced southwards from Delaware and Maryland to Georgia and Alabama. They also occur in Louisiana and other states both east and west of the valley of the Mississippi. At Claiborne, in Alabama, no less than 400 species of marine shells, with many echinoderms and teeth of fish, characterise one member of this system. Among the shells, the *Cardita planicosta*, before mentioned (fig. 194, p. 243), is in abundance ; and this fossil and some others identical with European species, or very nearly allied to them, make it highly probable that the Claiborne beds agree in age with the central or Bracklesham group of England, and with the calcaire grossier of Paris.[2]

Higher in the series is a remarkable calcareous rock, formerly called 'the nummulite limestone,' from the great number of discoid bodies resembling nummulites which it contains—fossils now referred by A. D'Orbigny to the genus *Orbitoides*, which has been demonstrated by Dr. Carpenter to belong to the foraminifera.[3] That naturalist, moreover, is of opinion that the Orbitoides alluded to (*O. Mantelli*) is of the same species as one found in Cutch in the Middle Eocene or nummulitic formation of India.

Above the orbitoidal limestone is a white limestone, sometimes soft and argillaceous, but in parts very compact and calcareous. It contains several peculiar corals, and a large Nautilus allied to *N. ziczac*; also in its upper bed a gigantic cetacean, called *Zeuglodon* by Owen.[1]

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[1] Murchison, Quart. Journ. of Geol. Soc., vol. v., and Lyell, vol. vi. 1850. Anniversary Address.

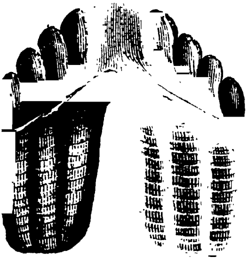
[2] See paper by the Author, Quart. Journ. Geol. Soc., vol. iv. p. 12; and Second Visit to the United States, vol. ii. p. 59.

[3] Quart. Journ. Geol. Soc., vol. vi p. 32.

The colossal bones of this cetacean are so plentiful in the interior of Clarke County, Alabama, as to be characteristic of the formation. The vertebral column of one skeleton found by Dr. Buckley at a spot visited by me, extended to the length of nearly seventy feet, and not far off part of another backbone nearly fifty feet long was dug up. I obtained evidence, during a short excursion, of so many localities of this fossil animal within a distance of ten miles, as to lead me to conclude that they must have belonged to at least forty distinct individuals.

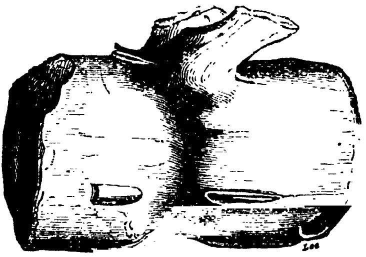
Prof. Owen first pointed out that this huge animal was not reptilian, since each tooth was furnished with double roots (fig. 230), implanted in corresponding double sockets; and his opinion of the cetacean nature of the fossil was afterwards confirmed by Dr. Wyman and Dr. R. W. Gibbes. That it was an extinct mammal of the whale tribe has since been placed beyond all doubt by the discovery of the entire skull of another fossil species of the same family, having the double occipital condyles only met with in mammals, and the convoluted tympanic bones which are characteristic of cetaceans.

Fig. 230.



Molar tooth, natural size.

Fig. 231.



Vertebra, reduced.

Zeuglodon cetoides, Owen.
Basilosaurus, Harlan.

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[1] See Memoir by R. W. Gibbes, Journ. of Acad. Nat. Sci. Philad., vol. i. 1847.

SECONDARY OR MESOZOIC SERIES.

CHAPTER XVII.

UPPER CRETACEOUS GROUP.

Lapse of time betwen Cretaceous and Eocene periods—Table of successive Cretaceous formations—Maestricht beds—Pisolitic limestone of France—Chalk of Faxoe—Geographical extent and origin of the White Chalk—Chalky matter now forming in the bed of the Atlantic—Marked difference between the Cretaceous and existing fauna—Chalk flints—Potstones of Horstead—Vitreous sponges in the Chalk—Isolated blocks of foreign rocks in the white chalk, supposed to be iceborne—Distinctness of mineral character in contemporaneous rocks of the Cretaceous epoch—Fossils of the white chalk—Lower white chalk without flints—Chalk Marl and its fossils—Chloritic series or Upper Greensand—Coprolite bed near Cambridge—Fossils of the Chloritic series—Gault—Connection between Upper and Lower Cretaceous strata—Blackdown beds—Flora of the Upper Cretaceous Period—Hippurite Limestone—Cretaceous rocks in the United States

We have treated in the preceding chapters of the Tertiary or Cainozoic strata, and have next to speak of the Secondary or Mesozoic formations. The uppermost of these last is commonly called the chalk or the cretaceous formation, from *creta*, the Latin name for that remarkable white, earthy limestone which constitutes an upper member of the group in those parts of Europe where it was first studied. The marked discordance in the fossils of the tertiary, as compared with the cretaceous formations, has long induced many geologists to suspect that an indefinite series of ages elapsed between the respective periods of their origin. Measured, indeed, by such a standard—that is to say, by the *amount of change in the Fauna and Flora of the earth effected in the interval—the time between the Cretaceous and Eocene* may have been as great as that between the Eocene and Recent periods, to the history of which the last seven chapters have been devoted. Several deposits have been met with here and there, in the course of the last half century, of an age intermediate between the white chalk and the plastic clays and sands of the Paris and London districts—monuments which have the same kind of interest to a geologist which certain mediæval records excite when we study the history of nations. For both of them throw light on ages of darkness, preceded and followed by others of which the annals are comparatively well known to us. But these newly-discovered records do not fill up the wide gap, some of them being closely allied to the Eocene, and others to the Cretaceous type, while none appear as yet to possess so distinct and characteristic a fauna as may entitle them to hold an independent place in the great chronological series.

Among the formations alluded to, the Thanet Sands of Prestwich have been sufficiently described in the last chapter, and classed as Lower Eocene. To the same tertiary series belong the Belgian formations, called by Professor Dumont, Landenian. On the other hand, the Maestricht and Faxoe limestones are very closely connected with the chalk, to which also the Pisolitic limestone of France is referable.

Classification of the Cretaceous rocks.—The Cretaceous group has generally been divided into an Upper and a Lower series, the Upper called familiarly *the chalk*, and the Lower *the greensand*; the one deriving its name from the predominance of white earthy limestone and marl, of which it consists in a great part of France and England, the other or Lower series from the plentiful mixture of green or chloritic grains contained in some of the sands and cherts of which it largely consists in the same countries. But these mineral characters often fail, even when we attempt to follow out the same continuous subdivisions throughout a small portion of the north of Europe, and are worse than valueless when we desire to apply them to more distant regions. It is only by aid of the organic remains which characterise the successive marine subdivisions of the formation that we are able to recognise in remote countries, such as the south of Europe or North America, the formations which were there contemporaneously in progress. To the English student of geology it will be sufficient to begin by enumerating those groups which characterise the series in this country and others immediately contiguous, alluding but slightly to those of more distant regions. In the annexed table it will be seen that I have used the term Neocomian for that commonly called 'Lower Greensand;' this latter term being peculiarly objectionable because the green grains are an exception to the rule in many of the members of this group even in districts where it was first studied and named. M. Alcide D'Orbigny, in his valuable work entitled 'Paléontologie Française,' has adopted new terms for the French subdivisions of the Upper Cretaceous series, and these are now so generally used by foreign writers that the student should endeavour to remember their relation to the

English equivalents so far as it is possible to make them agree.

UPPER CRETACEOUS OR CHALK PERIOD.

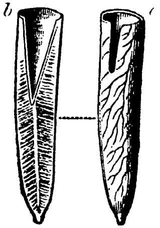
English subdivisions.	French equivalents.
1. Maestricht Beds, Faxoe Limestone, and Pisolitic Limestone of France.	1. Étage Danien.
2. Upper White Chalk, with flints.	2. Sénonien in part.
3. Lower White Chalk, without flints.	3. Sénonien in part.
4. Chalk Marl.	4. Sénonien in part and Turonien.
5. Chloritic series (or Upper Greensand).	5. Cénomanien.
6. Gault.	6. Albien.

LOWER CRETACEOUS OR NEOCOMIAN.

(Néocomien of the French.)[1]

Marine.	Freshwater.
1. Upper Neocomian, see p. 292.	Wealden Beds (upper part).
2. Middle Neocomian, see p. 296.	
3. Lower Neocomian, see p. 297.	

Fig. 232.



Belemnitella mucronata, Maestricht, Faxoe, and White Chalk.
a. Osselet or guard, showing vascular impressions on outer surface, with characteristic slit, and mucro.
b. Section of same, showing place of phragmocone.[2]

Maestricht Beds.—On the banks of the Meuse, at Maestricht, reposing on ordinary white chalk with flints, we find an upper calcareous formation about 100 feet thick, the fossils of which are, on the whole, very peculiar, and all distinct from Tertiary species. Some few are of species common to the inferior white chalk, among which may be mentioned *Belemnitella mucronata* (fig. 232) and *Pecten quadricostatus*, a shell regarded by many as a mere variety of *P. quinquecostatus* (see fig. 276, p. 284). Besides the Belemnite there are other *genera*, such as *Baculites* and *Hamites* never found in strata newer than the cretaceous, but frequently met with in these Maestricht beds. On the other hand, *Voluta*, *Fasciolaria*, and other genera of univalve shells occur, which are usually met with only in tertiary strata.

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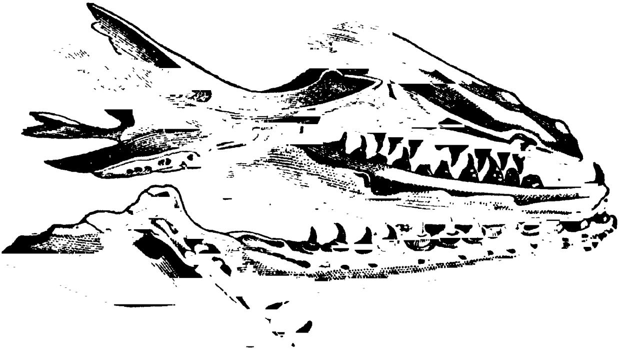
[1] The Lower Cretaceous or Neocomian is also called Neocomien by the French; the name Aptien formerly adopted by D'Orbigny for the Upper Neocomian, being now but rarely used.

[2] For particulars of structure, see p. 327.

The upper part of the rock, about 20 feet thick, as seen in St. Peter's Mount, in the suburbs of Maestricht, abounds in corals and Polyzoa, often detachable from the matrix ; and these beds are succeeded by a soft yellowish limestone 50 feet thick; extensively quarried from time immemorial for building. The stone below is whiter, and contains occasional nodules of grey chert or chalcedony.

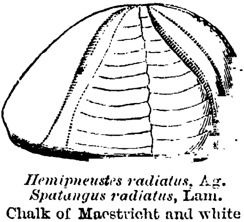
M. Bosquet, with whom I examined this formation (August, 1850), pointed out to me a layer of chalk from two to four inches thick, containing green earth and numerous encrinital stems, which forms the line of demarcation between the strata containing the fossils peculiar to Maestricht and the white chalk below. The latter is distinguished by regular layers of black flint in nodules, and by shells, such as *Terebratula carnea* (see fig. 252, p. 277), wholly wanting in beds higher than the green band. Some of the organic remains, however, for which St. Peter's Mount is celebrated, occur both above and below that parting layer, and, among others, the great marine reptile called *Mosasaurus* (see fig. 233), a saurian supposed to have been 24 feet in length, of which the entire skull and a great part of the skeleton have been found. Such remains are chiefly met with in the soft freestone, the principal member of the Maestricht

Fig. 233.



Mosasaurus Camperi. Original more than three feet long.

Fig. 234.



Hemipneustes radiatus, Ag.
Spatangus radiatus, Lam.
Chalk of Maestricht and white chalk.

beds. Among the fossils common to the Maestricht and white chalk may be instanced the echinoderm (fig. 234).

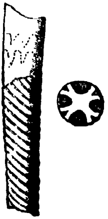
I saw proofs of the previous denudation of the white chalk exhibited in the lower bed of the Maestricht formation in Belgium, about 30 miles S.W. of Maestricht, at the village of Jendrain, where the base of the newer deposit consisted chiefly of a layer of well-rolled, black, chalk-flint pebbles, in the midst of which perfect specimens of *Thecidea pappillata* and *Belemnitella mucronata* are embedded. To a geologist accustomed in England to regard rolled pebbles of chalk-flint as a common and distinctive feature of tertiary beds of different ages, it is a new and surprising phenomenon to behold strata made up of such materials and yet to feel no doubt that they were accumulated in a sea in which the belemnite and other cretaceous mollusca flourished.

Pisolitic limestone of France.—Geologists were for many years at variance respecting the chronological relations of this rock, which is met with in the neighbourhood of Paris, and at places north, south, east, and west of that metropolis, as between Vertus and Laversines, Meudon and Montereau. By many able palæontologists the species of fossils, more than 50 in number, were declared to be more Eocene in their appearance than Cretaceous. But M. Hébert found in this formation at Montereau near Paris, the *Pecten quadricostatus*, a well-known Cretaceous species, together with some other fossils common to the Maestricht chalk and to the Baculite limestone of the Cotentin in Normandy. He therefore, as well as M. Alcide d'Orbigny, who had carefully studied the fossils, came to the opinion that it was an upper member of the Cretaceous group. It is usually in the form of a coarse yellowish or whitish limestone, and the total thickness of the series of beds already known is about 100 feet. Its geographical range, according to M. Hébert, is not less than 45 leagues from east to west, and 35 from north to south. Within these limits it occurs in small patches only, resting unconformably on the white chalk.

The *Nautilus Danicus* (fig. 236), and two or three other species found in this rock, are frequent in that of Faxoe in Denmark, but as yet no Ammonites, Hamites, Scaphites, Turrilites, Baculites, or Hippurites have been met with. The proportion of peculiar species, many of them of tertiary aspect, is confessedly large ; and great aqueous erosion suffered by the white chalk, before the pisolitic limestone was formed, affords an additional indication of the two deposits being widely separated in time. The pisolitic formation, therefore, may eventually prove to be somewhat more intermediate in date between the secondary and tertiary epochs than the Maestricht rock.

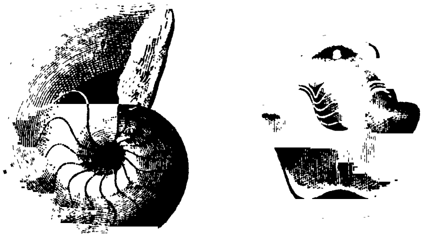
Chalk of Faxoe.—In the island of Seeland, in Denmark, the newest member of the chalk series, seen in the sea-cliffs at Stevensklint resting on white chalk with flints, is a yellow limestone, a portion of which, at Faxoe, where it is used as a building-stone, is composed of corals, even more conspicuously than is usually observed in recent coral reefs. It has been quarried to the depth of more than 40 feet, but its thickness is unknown. The embedded shells are chiefly casts, many of them of univalve mollusca, which are usually very rare in the white chalk of Europe. Thus, there are two species of *Cypræa*, one of *Oliva*, two of *Mitra*, four of the genus *Cerithium*, six of *Fusus*, two of *Trochus*, one of *Patella*, one of *Emarginula*, &c. ; on the whole, more than thirty univalves, spiral or patelliform. At the same time, some of the accompanying bivalve shells, echinoderms, and zoophytes are specifically identical with fossils of the true Cretaceous series. Among the cephalopoda of Faxoe may be mentioned *Baculites Faujasii* (fig. 235), and *Belemnitella mucronata* (fig. 232, p. 266), shells of the white chalk. The *Nautilus Danicus* (see fig. 236) is characteristic of this formation ; and it also occurs in France in the calcaire pisolitique of Laversin (Department of Oise). The claws and entire skull of a small crab, *Brachyurus rugosus* (Schlott.), are scattered through the Faxoe stone, reminding us of similar crustaceans enclosed in the rocks of modern coral reefs. Some small portions of this coral formation consist of white earthy chalk.

Fig. 235.



Portion of *Baculites Faujasii*, Sow. Maestricht and Faxoe beds and white chalk.

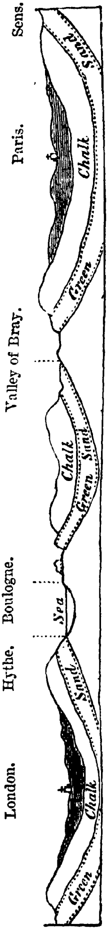
Fig. 236.



Nautilus Danicus, Schl. Faxoe, Denmark.

Composition, extent, and origin of the White Chalk.—The highest beds of chalk in England and France consist of a pure, white calcareous mass, usually too soft for a building-stone, but sometimes passing into a more solid state. It consists, almost purely, of carbonate of lime ; the stratification is often obscure, except where rendered distinct by interstratified layers of flint, a few inches thick, occasionally in continuous beds, but oftener in nodules, and recurring at intervals generally from two to four feet distant from each other. This upper chalk is usually succeeded, in the descending order, by a great mass of white chalk without flints, below which comes the chalk marl, in which there is a slight admixture of argillaceous matter. The united thickness of the three divisions in the south of England equals, in some places, 1,000 feet. The annexed section (fig. 237) will show the manner in which the white chalk extends from England into France, covered by the tertiary strata described in former chapters, and reposing on lower cretaceous beds.

Fig. 237.



Diagrammatic section from Hertfordshire, in England, to Sens, in France.

The area over which the white chalk preserves a nearly homogeneous aspect is so vast, that the earlier geologists despaired of discovering any analogous deposits of recent date. Pure chalk, of nearly uniform aspect and composition, is met with in a north-west and south-east direction, from the north of Ireland to the Crimea, a distance of about 1,140 geographical miles; and in an opposite direction it extends from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles. In southern Russia, according to Sir R. Murchison, it is sometimes 600 feet thick, and retains the same mineral character as in France and England with the same fossils, including *Inoceramus Cuvieri*, *Belemnitella mucronata*, and *Ostrea vesicularis* (fig. 257, p. 278).

Much light has recently been thrown upon the origin of the unconsolidated white chalk by the deep soundings made in the North Atlantic, previous to laying down, in 1858, the electric telegraph between Ireland and Newfoundland. At depths sometimes exceeding two miles, the mud forming the floor of the ocean was found, by Professor Huxley, to be almost entirely composed (more than nineteen-twentieths of the whole) of minute Rhizopods or foraminiferal shells of the genus *Globigerina*, especially the species *Globigerina bulloides* (see fig. 238). The organic bodies next in quantity were the siliceous shells called *Polycystineæ,* and next to them the siliceous skeletons of plants called *Diatomaceæ* (figs. 239, 240, 241), and occasionally some siliceous spiculæ of sponges (fig. 242) were intermixed. These were connected by a mass of living gelatinous matter to which he has given the name of *Bathybius*, and which contains abundance of very minute bodies termed Coccoliths and Coccospheres, which have also been detected fossil in chalk, though their true nature is not yet made out.

Fig. 238.

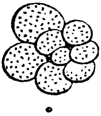


Fig. 239.

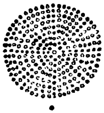


Fig. 240.

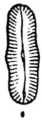


Fig. 241.

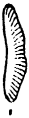


Fig. 242.

Organic bodies forming the ooze of the bed of the Atlantic at great depths.

Fig. 238. *Globigerina bulloides.* *Calcareous Rhizopod.*
239. *Actinocyclus.*
240. *Pinnularia.* } *Siliceous Diatomaceæ.*
241. *Eunotia bidens.*
242. *Spicula* of sponge. *Siliceous sponge.*

Sir Leopold MacClintock and Dr. Wallich have ascertained that 95 per cent. of the mud of a large part of the North Atlantic consists of the shells of Globigerina. But Capt. Bullock, R.N., lately brought up from the enormous depth of 16,860 feet a white, viscid, chalky mud, wholly devoid of Globigerinæ. This mud was perfectly homogeneous in composition, and contained no organic remains visible to the naked eye. Mr. Etheridge, however, has ascertained by microscopical examination that it is made up of *Coccoliths*, *Discoliths*, and other minute fossils like those of the Chalk classed by Huxley as *Bathybius*, when this term is used in its widest sense. This white mud, more than three miles deep, was dredged up in lat. 20° 19′ N., long. 4° 36′ E., or about midway between Madeira and the Cape of Good Hope.

The recent deep-sea dredgings in the Atlantic conducted by Dr. Wyville Thomson,[1] Dr. Carpenter, Mr. Gwyn Jeffreys, and others have shown that on the same white mud there sometimes flourish Mollusca, Crustacea and Echinoderms, besides abundance of siliceous sponges, forming on the whole a marine fauna bearing a striking resemblance in its general character to that of the ancient chalk.

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[1] An interesting account of the results of the dredging cruises will be found in Dr. Wyville Thomson's admirable work 'The Depths of the Sea.' 1873.

Popular error as to the geological continuity of the Cretaceous period.—We must be careful, however, not to overrate the points of resemblance which the deep-sea investigations have placed in a strong light. They have been supposed by some naturalists to warrant a conclusion expressed in these words: 'we are still living in the Cretaceous epoch'; a doctrine which has led to much popular delusion as to the bearing of the new facts on geological reasoning and classification. The reader should be reminded that in geology we have been in the habit of founding our great chronological divisions, not on foraminifera and sponges, nor even on echinoderms and corals, but on the remains of the most highly organised beings available to us, such as the mollusca; these being met with, as above explained (p. 119), in stratified rocks of almost every age. In dealing with the mollusca, it is those of the highest or most specialised organisation which afford us the best characters in proportion as their vertical range is the most limited. Thus the Cephalopoda are the most valuable as having a more restricted range in time than the Gasteropoda, and these again are more characteristic of the particular stratigraphical subdivisions than are the Lamellibranchiate Bivalves, while these last again are more serviceable in classification than the Brachiopoda, a still lower class of shell-fish, which are the most enduring of all.

When told that the new dredgings prove that 'we are still living in the Chalk Period,' we naturally ask whether some cuttle-fish has been found with a belemnite forming part of its internal framework; or have Ammonites, Baculites, Hamites, Turrilites, with four or five other Cephalopodous genera characteristic of the chalk and unknown as tertiary, been met with in the abysses of the ocean? Or, in the absence of these long-extinct forms, has a single spiral univalve, or species of Cretaceous Gasteropod, been found living? Or, to descend still lower in the scale, has some characteristic Cretaceous genus of Lamellibranchiata, such as the Inoceramus, or Hippurite, foreign to the Tertiary seas, been proved to have survived down to our time? Or of the numerous genera of Lamellibranchiata common to the Cretaceous and Recent seas, has one species been found living? The answer to all these questions is—not one has been found. Even amongst the lowly-organised Brachiopods, no species common to the Cretaceous and Recent seas has yet been met with. It has been very generally admitted by conchologists that out of a hundred species of this tribe occurring fossil in the Upper Chalk—one and one only, *Terebratulina striata*, is still living, being thought to be identical with *Terebratula caput-serpentis.* Although this identity is still questioned by some naturalists of authority, it would certainly not surprise us if other 'lamp-shells' of equal antiquity should be met with in the deep sea.

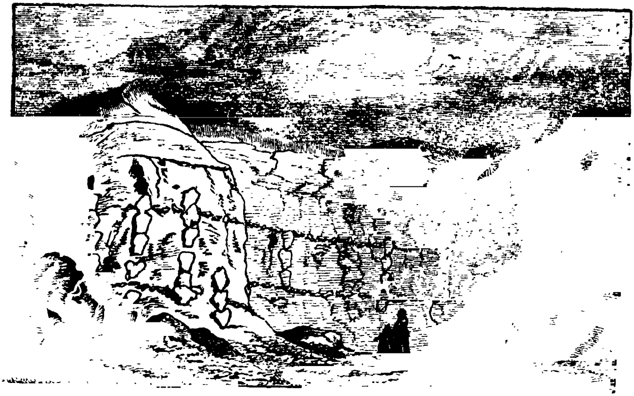
Had it been declared that we are living in the Eocene epoch, the idea would not be so extravagant, for the great reptiles of the Upper Chalk, the Mosasaurus, Pliosaurus, and Pterodactyle, and many others, as well as so many genera of chambered univalves, had already disappeared from the earth, and the marine fauna had made a greater approach to our own by nearly the entire difference which separates it from the fauna of the Cretaceous seas. The Eocene nummulitic limestone of Egypt is a rock mainly composed, like the more ancient white chalk, of globigerine and textularian mud; and if the reader will refer to what we have said of the extent to which the nummulitic marine strata, formed originally at the bottom of the sea, now form part of the framework of mountain chains of the principal continents, he will at once perceive that the present Atlantic, Pacific, and Indian Oceans are geographical terms, which must be wholly without meaning when applied to the Eocene, and still more to the Cretaceous Period; so that to talk of the chalk having been uninterruptedly forming in the Atlantic from the Cretaceous Period to our own, is as inadmissible in a geographical as in a geological sense.

Chalk flints.—The origin of the layers of flint, whether in the form of nodules, or continuous sheets, or in veins or cracks not parallel to the stratification, has always been more difficult to explain than that of the white chalk. But here again the late deep-sea soundings have suggested a possible source of such mineral matter. During the cruise of the 'Bulldog,' already alluded to, it was ascertained that while the calcareous *Globigerinæ* had almost exclusive possession of certain tracts of the sea-bottom, they were wholly wanting in others, as between Greenland and Labrador. According to Dr. Wallich, they may flourish in those spaces where they derive nutriment from organic and other matter, brought from the south by the warm waters of the Gulf Stream, and they may be absent where the effects of that great current are not felt. Now in several of the spaces where the calcareous Rhizopods are wanting, certain microscopic plants, called *Diatomaceæ*, above mentioned (figs. 239–241), the solid parts of which are siliceous, monopolise the area at a depth of nearly 400 fathoms, or 2,400 feet.

The large quantities of silex in solution required for the formation of these plants may probably arise from the disintegration of felspathic rocks, which are universally distributed. As more than half of their bulk is formed of siliceous earth, they may afford an endless supply of silica to all the great rivers which flow into the ocean. We may imagine that after a lapse of many years or centuries, changes took place in the direction of the marine currents, favouring at one time a supply in the same area of siliceous, and at another of calcareous matter in excess, giving rise in the one case to a preponderance of Diatomaceæ, and in the other of Globigerinæ. These last, together with certain sponges, may by their decomposition have furnished the silex, which, separating from the chalky mud, collected round organic bodies, or formed nodules or filled shrinkage cracks.

Potstones. Vitreous sponges of the Chalk.—A more difficult enigma is presented by the occurrence of certain huge flints, or potstones, as they are called in Norfolk, occurring singly, or arranged in nearly continuous columns at right angles to the ordinary and horizontal layers of small flints. I visited in the year 1825 an extensive range of quarries then open on the river Bure, near Horstead, about six miles from Norwich, which afforded a continuous section, a quarter of a mile in length, of white chalk, exposed to the depth of about twenty-six feet, and covered by a bed of gravel. The potstones, many of them pear-shaped, were usually about three feet in height and one foot in their transverse diameter, placed in vertical rows, like pillars, at irregular distances from each other, but usually from twenty to thirty feet apart, though sometimes

Fig. 243.



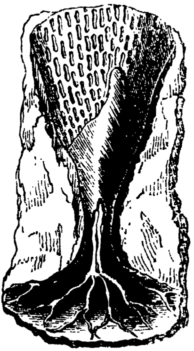
From a drawing by Mrs. Gunn.

View of a chalk-pit at Horstead, near Norwich, showing the position of the potstones.

nearer together, as in the above sketch. These rows did not terminate downwards in any instance which I could examine, nor upwards, except at the point where they were cut off abruptly by the bed of gravel. On breaking open the potstones, I found an internal cylindrical nucleus of pure chalk, much harder than the ordinary surrounding chalk, and not crumbling to pieces, like it, when exposed to the winter's frost. At the distance of half a mile, the vertical piles of potstones were much farther apart from each other. Dr. Buckland has described very similar phenomena as characterising the white chalk on the north coast of Antrim, in Ireland.[1] These pear-shaped masses of flint often resemble in shape and size the large sponges called Neptune's Cups (*Spongia patera*, Hardw.), which grow in the seas of Sumatra ; and if we could suppose a series of such gigantic sponges to be separated from each other, like trees in a forest, and the individuals of each successive generation to grow on the exact spot where the parent sponge died and was enveloped in calcareous mud, so that they should become piled one above the other in a vertical column, their growth keeping pace with the accumulation of the enveloping calcareous mud, a counterpart of the phenomena of the Horstead potstones might be obtained.

Professor Wyville Thomson, describing the modern soundings in 1869 off the north coast of Scotland, speaks of the ooze or chalk mud brought from a depth of about 3,000 feet, and states that at one haul they obtained forty specimens of vitreous sponges buried in the mud. He suggests that the Ventriculites of the chalk were nearly allied to these sponges, and that when the silica of their spicules was removed, and was dissolved out of the calcareous matrix, it set into flint.[2]

Fig. 211.



Ventriculites radiatus. Mantell. Syn. *Ocellaria radiata.* D'Orb.
White chalk.

Boulders and groups of pebbles in chalk.—The occurrence here and there in the white chalk of the south of England of isolated pebbles of quartz and green schist has justly excited much wonder. It was at first supposed that they had been dropped from the roots of some floating tree, by which means stones are carried to some of the small coral islands of the Pacific. But the discovery in 1857 of a group of stones in the white chalk near Croydon, the largest of which was syenite and weighed about forty pounds, accompanied by pebbles and fine sand like that of a beach, has been shown by Mr. Godwin Austen to be inexplicable except by the agency of floating ice. If we consider that icebergs now reach 40° north latitude in the Atlantic, and several degrees nearer the equator in the southern hemisphere, we can the more easily believe that even during the Cretaceous epoch, assuming that the climate was milder, fragments of coast ice may have floated occasionally as far as the south of England.

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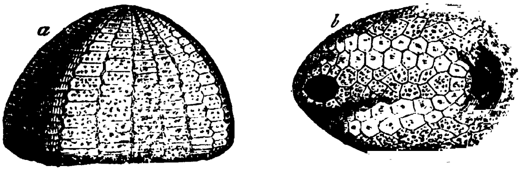
[1] Geol. Trans., 1st Series, vol. iv. p. 413.

[2] See also 'Depths of the Sea,' 1873, p. 482.

Distinctness of mineral character in contemporaneous rocks of the Cretaceous period.—But we must not imagine that because pebbles are so rare in the white chalk of England and France there are no proofs of sand, shingle, and clay having been accumulated contemporaneously even in European seas. The siliceous sandstone, called 'upper quader' by the Germans, overlies white argillaceous chalk, or 'pläner-kalk,' a deposit resembling in composition and organic remains the chalk marl of the English series. This sandstone contains as many fossil shells common to our white chalk as could be expected in a sea-bottom formed of such different materials. It sometimes attains a thickness of 600 feet, and, by its jointed structure and vertical precipices, plays a conspicuous part in the picturesque scenery of Saxon Switzerland, near Dresden. It demonstrates that in the Cretaceous sea, as in our own, distinct mineral deposits were simultaneously in progress. The quartzose sandstone alluded to, derived from the detritus of the neighbouring granite, is absolutely devoid of carbonate of lime, yet it was formed at the distance only of four hundred miles from a sea-bottom now constituting part of France, where the purely calcareous white chalk was forming. In the North American continent, on the other hand, where the Upper Cretaceous formations are so widely developed, true white chalk, in the ordinary sense of that term, does not exist.

Fig. 245.

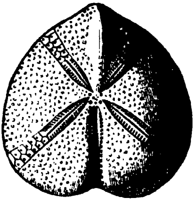


Ananchytes ovatus, Leske. White chalk, upper and lower.

a. Side view. *b.* Base of the shell on which both the oral and anal apertures are placed; the anal being more round, and at the smaller end.

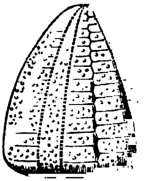
Fossils of the White Chalk.—Among the fossils of the white chalk, echinoderms are very numerous; and some of the genera, like *Ananchytes* (see fig. 245), are exclusively cretaceous.

Fig. 246.



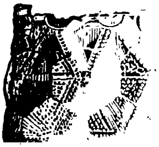
Micraster cor-anguinum, Leske. White chalk.

Fig. 247.



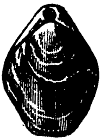
Galerites albogalerus, Lam. White chalk.

Fig. 248.



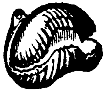
Marsupites Milleri, Mant. White chalk.

Fig. 249.



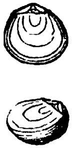
Terebratulina striata, Wahlenb. Upper white chalk.

Fig. 250.



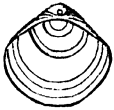
Rhynchonella octoplicata, Sow. (Var. of *R. plicatilis*.) Upper white chalk.

Fig. 251.



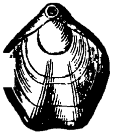
Magas pumila, Sow. Upper white chalk.

Fig. 252.



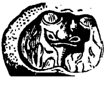
Terebratula carnea Sow. Upper white chalk

Fig. 253.



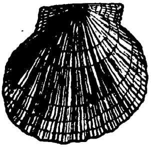
Terebratula biplicata, Brocchi. Upper Cretaceous.

Fig. 254.



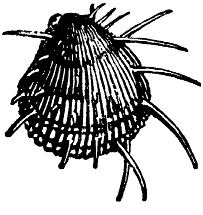
Crania Parisiensis, Duf. Inferior or attached valve. Upper white chalk.

Fig. 255.



Pecten Beaveri, Sow. Reduced to one-third diameter. Lower white chalk and chalk marl.

Fig. 256.

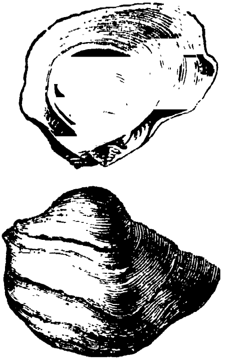


Lima spinosa, Sow. Syn. *Spondylus spinosus*. Upper white chalk.

Among the Crinoidea, the *Marsupites* (fig. 248) is a characteristic genus. Among the mollusca, the cephalopoda are represented by Ammonites, Baculites (fig. 235, p. 269), and Belemnites (fig. 232, p. 266). Although there are eight or more species of Ammonites and six of them peculiar to it, this genus is much less fully represented than in each of the other subdivisions of the Upper Cretaceous group.

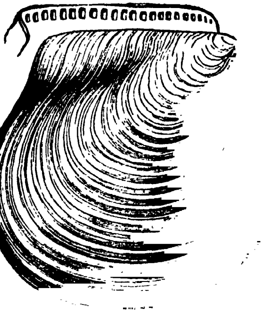
Among the brachiopoda in the white chalk, the *Terebratulæ* are very abundant (see figs. 249, 252, 253). With these are associated some forms of oyster (see fig. 257), and other bivalves (figs. 255, 256).

Fig. 257.



Ostrea vesicularis. Syn. *Gryphæa convexa.*
Upper chalk and Upper greensand.

Fig. 258.



Inoceramus Lamarckii.
Syn. *Catillus Lamarckii.*
White chalk (Dixon's Geol. Sussex, tab. 28, fig. 29).

Fig. 259.

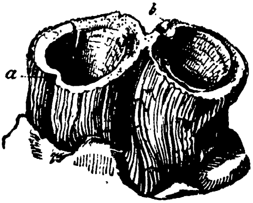


Fig. 260.

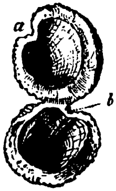


Fig. 261.

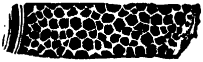
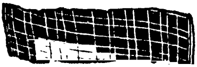


Fig. 262.



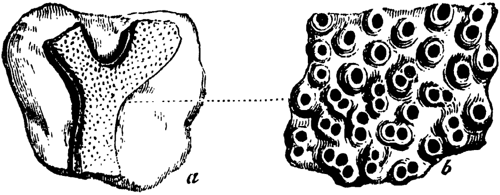
Radiolites Mortoni, Mantell. Houghton, Sussex. White chalk.
Diameter one-seventh nat. size.

Fig. 259. Two individuals deprived of their upper valves, adhering together.
260. Same seen from above.
261. Transverse section of part of the wall of the shell, magnified to show the structure.
262. Vertical section of the same.

On the side where the shell is thinnest, there is one external furrow and corresponding internal ridge, *a*, *b*, figs. 259, 260; but they are usually less prominent than in these figures. The upper or opercular valve is wanting.

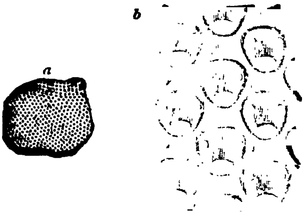
Among the bivalve mollusca, no form marks the Cretaceous era in Europe, America, and India in a more striking manner than the extinct genus *Inoceramus* (*Catillus* of Lam.; see fig. 258), the shells of which are distinguished by a fibrous texture, and are often met with in fragments, having probably been extremely friable.

Fig. 263.



Eschara disticha. White chalk.
a. Natural size. *b.* Portion magnified.

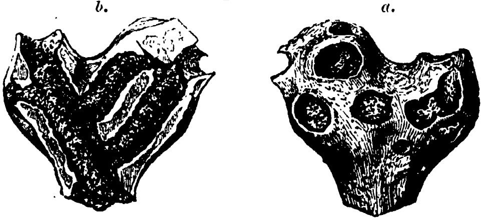
Fig. 264.



a. Natural size.
b. Part of the same magnified.

White chalk.

Fig. 265.



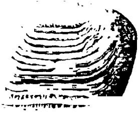
A branching sponge in a flint, from the white chalk.
From the collection of Mr. Bowerbank.

Of the singular order called *Rudistes*, by Lamarck, hereafter to be mentioned, as extremely characteristic of the chalk of southern Europe, one species only (fig. 259) has been discovered in the white chalk of England.

The general absence of univalve mollusca in the white chalk is very marked. Of polyzoa there is an abundance, such as *Eschara* and *Escharina* (figs. 263, 264). These and other organic bodies, especially sponges, such as *Ventriculites* (fig. 244, p. 275), are dispersed indifferently through the soft chalk and hard flint, and some of the flinty nodules owe their irregular forms to enclosed sponges, such as fig. 265, *a*, where the hollows in the exterior are caused by the branches of a sponge (fig. 265, *b*), seen on breaking open the flint.

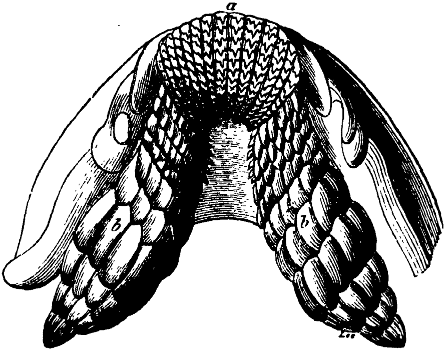
The remains of fishes of the Upper Cretaceous formations consist chiefly of teeth belonging to the shark family. Some of the genera are common to the Tertiary formations, but many are distinct. To the latter belongs the genus *Ptychodus* (fig. 266), which is allied to the living Port Jackson shark, *Cestracion Phillippi*, the anterior teeth of which (see fig. 267, *a*) are sharp and cutting, while the posterior or palatal teeth (*b*) are flat (fig. 266). But we meet with no bones of land animals, nor any terrestrial or fluviatile shells, nor any plants, except sea-weeds, and here and there a piece of drift-wood. All the appearances concur in leading us to conclude that the white chalk was the product of an open sea of considerable depth.

Fig. 266.



Palatal tooth of *Ptychodus decurrens*. Lower white chalk. Maidstone.

Fig. 267.

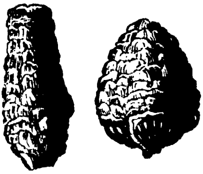


Cestracion Phillippi; recent. Port Jackson. Buckland. Bridgwater Treatise, Pl. 27, *d*.

The existence of turtles and oviparous saurians, and of a Pterodactyl or winged lizard, found in the white chalk of Maidstone, implies, no doubt, some neighbouring land; but a few small islets in mid-ocean, like Ascension, formerly so much frequented by migratory droves of turtle, might perhaps have afforded the required retreat where these creatures laid their eggs in the sand, or from which the flying species may have been blown out to sea. Of the vegetation of such islands we have scarcely any indication, but it consisted partly of cycadaceous plants; for a fragment of one of these was found by Capt. Ibbetson in the Chalk Marl of the Isle of Wight, and is referred by A. Brongniart to *Clathraria Lyellii* (Mantell), a species common to the antecedent Wealden period. The fossil plants, however, of beds corresponding in age to the white chalk at Aix-la-Chapelle, presently to be described, like the sandy beds of Saxony, before alluded to (p. 276), afford such evidence of land as to prove how vague must be any efforts of ours to restore the geography of that period.

The Pterodactyl of the Kentish chalk, above alluded to, was of gigantic dimensions, measuring 16 feet 6 inches from tip to tip of its outstretched wings. Some of its elongated bones were at first mistaken by able anatomists for those of birds; of which class no osseous remains have as yet been derived from the white chalk, although they have been found (as will be seen at page 283) in the Chloritic sand.

Fig. 268.

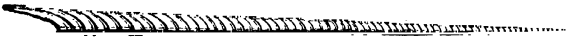


Coprolites of fish, from the chalk.

The collector of fossils from the white chalk was formerly puzzled by meeting with certain bodies which were called larch-cones, which were afterwards recognised by Dr. Buckland to be the excrement of fish (see fig. 268). They are composed in great part of phosphate of lime.

Lower White Chalk.—The Lower White Chalk, which is several hundred feet thick, without flints, has yielded 25 species of Ammonites, of which half are peculiar to it. The genera Baculite, Hamite, Scaphite, Turrilite, Nautilus, Belemnitella, and Belemnite, are also represented.

Fig. 269.

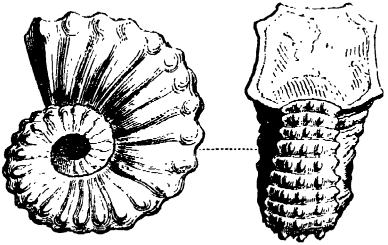


Baculites anceps, Lam. Lower chalk.

Chalk Marl.—The lower chalk without flints passes gradually downwards, in the south of England, into an argillaceous limestone, 'the chalk marl,' already alluded to (p. 282). It contains 32 species of Ammonites, 7 of which are peculiar to it, while 11 pass up into the overlying lower white chalk. *A. Rhotomagensis* (fig. 270) is characteristic of this formation. Among the British cephalopods of other genera may be mentioned

Scaphites æqualis (fig. 272) and the spiral and sinistral *Turrilites costatus* (fig. 271).

Fig. 270.



Ammonites Rhotomagensis. Chalk marl. Back and side view.

Fig. 271.

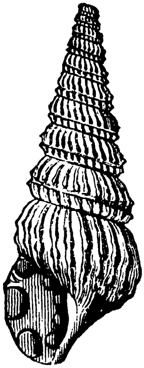
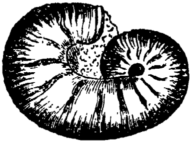
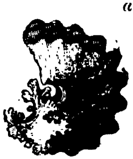


Fig. 272.



Scaphites æqualis.
Chloritic marl and sand, Dorsetshire.



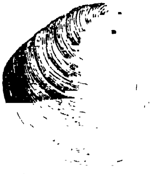
Turrilites costatus, Lam. Lower chalk and chalk marl.
a. Section, showing the foliated border of the sutures of the chambers.

Chloritic series (or Upper Greensand).—According to the old nomenclature, this subdivision of the chalk was called Upper Greensand, in order to distinguish it from those members of the Neocomian or Lower Cretaceous series below the Gault to which the name of Greensand had been applied. Besides the reasons before given (p. 265) for abandoning this nomenclature, it is objectionable in this instance as leading the uninitiated to suppose that the divisions thus named, Upper and Lower Greensand, are of co-ordinate value, instead of which the chloritic sand is quite a subordinate member of the Upper Cretaceous group, and the term Greensand has very commonly been used for the whole of the Lower Cretaceous rocks, which are almost comparable in importance to the entire Upper Cretaceous series. The higher portion of the Chloritic series in some districts has been called chloritic marl, from its consisting of a chalky marl with chloritic grains. In parts of Surrey where calcareous matter is largely intermixed with sand, it forms a stone called malm-rock or fire-stone. In the cliffs of the southern coast of the Isle of Wight it contains bands of calcareous limestone with nodules of chert.

Coprolite bed.—The so-called coprolite bed, found near Farnham, in Surrey, and near Cambridge, contains nodules of phosphate of lime in such abundance as to be largely worked for the manufacture of artificial manure. It belongs to the lower part of the chloritic series, and is doubtless chiefly of animal origin, and may perhaps be partly coprolitic, derived from the excrement of fish and reptiles. The late Mr. Barrett discovered in it, near Cambridge, in 1858, the remains of a bird, which was rather larger than the common pigeon, and probably of the order Natatores, and which, like most of the Gull tribe, had well-developed wings. Portions of the tibia, femur, and some other bones have been detected, and the determinations of Mr. Barrett have been confirmed by Professor Owen.

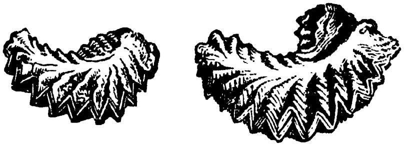
The phosphatic bed in the suburbs of Cambridge must have been formed partly by the denudation of pre-existing rocks, mostly of Lower Cretaceous age. The fossil shells and bones of animals washed out of these denuded strata, especially the Gault, now forming a layer only a few feet thick, have yielded a rich harvest to the collector. A large Radiolite of the order Rudistes, no less than two feet in height, may be seen in the Cambridge Museum, obtained from this bed. The number of reptilian remains, all apparently of Cretaceous age, is truly surprising; more than ten species of Pterodactyle, five or six of Icthyosaurus, one of Pliosaurus, one of Dinosaurus, eight of Chelonian, besides other forms, having been recognised.

Fig. 273.



Ostrea columba.
Syn. *Gryphæa columba.*
Chloritic sand.

Fig. 274.

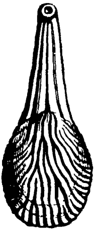


Ostrea carinata.
Chalk marl and chloritic sand. Neocomian.

The chloritic sand is regarded by many geologists as a littoral deposit of the Chalk Ocean, and, therefore, contemporaneous with part of the chalk marl, and even, perhaps, with some part of the white chalk. For, as the land went on sinking, and the cretaceous sea widened its area, white mud and chloritic sand were always forming somewhere, but the line of sea-shore was perpetually shifting its position. Hence, though both sand and mud originated simultaneously, the one near the land, the other far from it, the sands in every locality where a shore became submerged might constitute the underlying deposit.

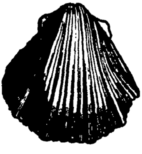
Among the characteristic mollusca of the chloritic sand may be mentioned *Terebrirostra lyra* (fig. 275), *Lima* (*Plagiostoma*) *Hoperi* (fig. 277), *Pecten quinquecostatus* (fig. 276), and *Ostrea columba* (fig. 273).

Fig. 275.



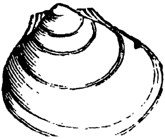
Terebrirostra lyra, Sow. Chloritic sand and marl.

Fig. 276.



Pecten 5-costatus. Lower white chalk and chloritic series.

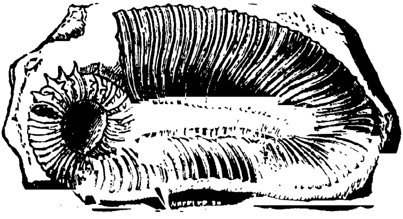
Fig. 277.



Lima (*Plagiostoma*) *Hoperi*, Sow. Syn. *Lima Hoperi.* White chalk and chloritic marl.

The cephalopoda are abundant, among which 40 species of Ammonites are now known, 10 being peculiar to this sub-division, and the rest common to the beds immediately above or below.

Fig. 278.



Ancyloceras spinigerum, D'Orb. Syn. *Hamites spiniger*, Sow. Near Folkestone. Gault.

Gault.—The lowest member of the Upper Cretaceous group, usually about 100 feet thick in the S.E. of England, is provincially termed Gault. It consists of a dark blue marl, sometimes intermixed with greensand. Many peculiar forms of cephalopoda, such as *Hamites* (fig. 278), and *Scaphites*, with remarkable *Ammonites* and other fossils, characterise this formation, which, small as is its thickness, can be traced by its organic remains to distant parts of Europe, as, for example, to the Alps.

21 species of Ammonites are recorded as found in the Gault of England, of which only 8 are peculiar to it, 10 being common to the overlying Chloritic series.

Connection between Upper and Lower Cretaceous strata —Blackdown Beds.—The break between the Upper and Lower Cretaceous formations will be appreciated when it is stated that, although the Neocomian contains 31 species of Ammonites, and the Gault, as we have seen, 21, there are only 3 of these common to both divisions. Nevertheless, we may expect the discovery in England, and still more when we extend our survey to the Continent, of beds of passage intermediate between the Upper and Lower Cretaceous. Even now the Blackdown beds in Devonshire, which rest immediately on Triassic strata, and which evidently belong to some part of the Cretaceous series, have been referred by some geologists to the Upper group, by others to the Lower or Neocomian. They resemble the Folkestone beds of the latter series in mineral character, and 59 out of 156 of their fossil mollusca are common to them; but they have also 16 species common to the Gault, and 20 to the overlying Chloritic series; and, what is very important, out of 7 Ammonites 6 are found also in the Gault and Chloritic series, only 1 being peculiar to the Blackdown beds.

Professor Ramsay has remarked that there is a stratigraphical break; for in Kent, Surrey, and Sussex, at those few points where there are exposures of junctions of the Gault and Neocomian, the surface of the latter has been much eroded or denuded, while to the westward of the great chalk escarpment the unconformability of the two groups is equally striking. At Blackdown this unconformability is still more marked, for, though distant only 100 miles from Kent and Surrey, no formation intervenes between these beds and the Trias; all intermediate groups, such as the Lower Neocomian and Oolite, having either not been deposited or destroyed by denudation.

Flora of the Upper Cretaceous period.—As the Upper Cretaceous rocks of Europe are, for the most part, of purely marine origin, and formed in deep water usually far from the nearest shore, land-plants of this period, as we might naturally have anticipated, are very rarely met with. In the neighbourhood of Aix-la-Chapelle, however, an important exception occurs, for there certain white sands and laminated clays, 400 feet in thickness, contain the remains of terrestrial plants in a beautiful state of preservation. These beds are the equivalents of the white chalk and chalk marl of England, or Sénonien of D'Orbigny, although the white siliceous sands of the lower beds, and the green grains in the upper part of the formation, cause it to differ in mineral character from our white chalk.

Beds of fine clay, with fossil plants, and with seams of lignite, and even perfect coal, are intercalated. Floating wood, containing perforating shells, such as Pholas and Gastrochœna, occur. There are likewise a few beds of a yellowish brown limestone, with marine shells, which enable us to prove that the lowest and highest plant-beds belong to one group. Among these shells are *Pecten quadricostatus*, and several others which are common to the upper and lower part of the series, and *Trigonia limbata* (D'Orbigny), a shell of the white chalk; and a Hamite, a form so characteristic of the Cretaceous formation, was recognised in 1873 by Prof. Hughes in M. Debey's collection. On the whole the organic remains and the geological position of the strata prove distinctly that in the neighbourhood of Aix-la-Chapelle, a gulf of the ancient Cretaceous sea was bounded by land composed of Devonian and Carboniferous rocks. These rocks consisted of quartzose and schistose beds, the first of which supplied white sand and the other argillaceous mud to a river which entered the sea at this point, carrying down in its turbid waters much drift-wood and the leaves of plants. Occasionally, when the force of the river abated, marine shells of the genera *Trigonia*, *Turritella*, *Pecten*, *Hamites*, &c., established themselves in the same area, and plants allied to *Zostera* and *Fucus* grew on the bottom.

The fossil plants of this member of the upper chalk at Aix have been diligently collected and studied by Dr. Debey, and as they afford the only example yet known of a terrestrial flora older than the Eocene, having the great divisions of the vegetable kingdom represented in nearly the same proportions as in our own times, they deserve particular attention. Dr. Debey estimates the number of species as amounting to more than 400, of which 70 or 80 are cryptogamous, chiefly ferns, 20 species of which can be well determined, most of them being in fructification. The scars on the bark of one or two are supposed to indicate tree-ferns. Of thirteen genera three are still existing, namely *Gleichenia*, now inhabiting the Cape of Good Hope and New Holland; *Lygodium*, now spread extensively through tropical regions, but having some species which live in Japan and North America; and *Asplenium*, a living cosmopolite form.

Among the phænogamous plants, the Conifers are abundant, the most common belonging to a genus called Cycadopsis by Debey, and hardly separable from Sequoia (or Wellingtonia), of which both the cones and branches are preserved. When I visited Aix, I found the silicified wood of this plant very plentifully dispersed through the white sands in the pits near that city. In one silicified trunk 200 rings of annual growth could be counted. Species of Araucaria like those of Australia are also found, and among the Monocotyledons there are some very peculiar types. No palms have been recognised with certainty, but 3 or 4 species of the genus Pandanus, or screw-pine, have been distinctly made out. The number of the Dicotyledonous Angiosperms is the most striking feature is so ancient a flora.[1]

Among them we find the familiar forms of the Oak (Cupuliferæ), the bog-myrtle (Myricaceæ) together with several genera of the Myrtaceæ. But the predominant order is the Proteaceæ, of which there are between 60 and 70 supposed species, some of extinct genera, but some referred to the following living forms—Dryandra, Grevillea, Hakea, Bellendina, Banksia, Persoonia—all now belonging to Australia, and Leucospermum, species of which form small bushes at the Cape.

The epidermis of the leaves of many of these Aix plants, especially of the Proteaceæ, is so perfectly preserved in an envelope of fine clay, that under the microscope the stomata, or polygonal cellules, can be detected, and their peculiar arrangement is identical with that known to characterise some living Proteaceæ (Grevillea, for example). Although this peculiarity of the structure of stomata is also found in plants of widely distant orders, it is, on the whole, but rarely met with, and, being thus

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[1] In this and subsequent remarks on fossil plants I shall often use Dr. Lindley's terms, as most familiar in this country; but as those of M. A. Brongniart are much cited, it may be useful to geologists to give a table explaining the corresponding names of groups so much spoken of in palæontology.

	Brongniart.	Lindley.	
Cryptogamic.	1. Cryptogamous amphigens, or cellular cryptogamic.	Thallogens.	Lichens, sea-weeds, fungi.
	2. Cryptogamous acrogens.	Acrogens.	Mosses, equisetums, ferns, lycopodiums,—Lepidodendra.
Phænerogamic.	3. Dicotyledonous gymnosperms.	Gymnogens.	Conifers and Cycads.
	4. Dicot. Angiosperms.	Exogens.	Compositæ, leguminosæ, umbelliferæ, cruciferæ, heaths, &c. All native European trees except Conifers.
	5.	Endogens.	Palms, lilies, aloes, rushes grasses, &c.

observed to characterise a foliage previously suspected to be proteaceous, it adds to the probability that the botanical evidence had been correctly interpreted.

An occasional admixture at Aix-la-Chapelle of Fucoids and Zosterites attests, like the shells, the presence of salt water. Of insects, Dr. Debey has obtained about ten species of the families Curculionidæ and Carabidæ.

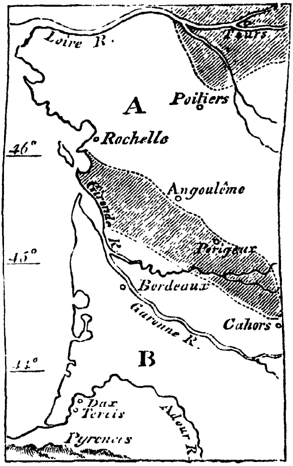
The resemblance of the flora of Aix-la-Chapelle to the tertiary and living floras in the proportional number of dicotyledonous angiosperms as compared to the gymnogens, is a subject of no small theoretical interest, because we can now affirm that these Aix plants flourished before the rich reptilian fauna of the secondary rocks had ceased to exist. The Ichthyosaurus, Pterodactyl, and Mosasaurus were of coeval date with the oak and Myrica. Speculations have often been hazarded respecting a connection between the rarity of Exogens in the older rocks and a peculiar state of the atmosphere. A denser air, it was suggested, had in earlier times been alike adverse to the well-being of the higher order of flowering plants, and of the quick-breathing animals, such as mammalia and birds, while it was favourable to a cryptogamic and gymnospermous flora, and to a predominance of reptile life. But we now learn that there is no incompatibility in the co-existence of a vegetation like that of the present globe, and some of the most remarkable forms of the extinct reptiles of the age of gymnosperms.

If the break between the flora of the Upper Cretaceous period and that of the Lower or Neocomian, as represented by the Wealden flora, seem at present to be somewhat sudden, the abruptness of the change will probably disappear when we are better acquainted with the fossil vegetation of the lowest strata of the Gault and that of the uppermost beds of the antecedent Neocomian.

Hippurite limestone.—*Difference between the chalk of the North and South of Europe.* By the aid of the three tests, superposition, mineral character, and fossils, the geologist has been enabled to refer to the same Cretaceous period certain rocks in the north and south of Europe, which differ greatly both in their fossil contents and in their mineral composition and structure.

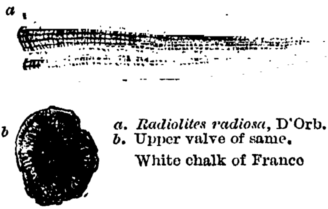
If we attempt to trace the cretaceous deposits from England and France to the countries bordering the Mediterranean, we perceive, in the first place, that in the neighbourhood of London and Paris they form one great continuous mass, the Straits of Dover being a trifling interruption, a mere valley with chalk cliffs on both sides. We then observe that the main body of the chalk which surrounds Paris stretches from Tours tonear Poitiers (see the annexed map, fig. 279, in which the shaded part represents chalk).

Fig. 279.



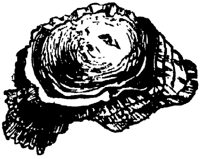
Between Poitiers and La Rochelle, the space marked A on the map separates two regions of chalk. This space is occupied by the Oolite and certain other formations older than the Chalk and Neocomian, and has been supposed by M. E. de Beaumont to have formed an island in the Cretaceous sea. South of this space we again meet with rocks which we at once recognise to be cretaceous, partly from the chalky matrix and partly from the fossils being very similar to those of the white chalk of the north: especially certain species of the genera *Spatangus*, *Ananchytes*, *Cidaris*, *Nucula*, *Ostrea*, *Gryphæa* (*Exogyra*), *Pecten*, *Lima*, *Trigonia*, *Catillus* (*Inoceramus*) and *Terebratula*.[1] But Ammonites, as M. D'Archiac observes, of which so many species are met with in the chalk of the north of France, are scarcely ever found in the southern region; while the genera *Hamite*, *Turrilite*, and *Scaphite*, and perhaps *Belemnite*, are entirely wanting.

Fig. 280.



a. *Radiolites radiosa*, D'Orb.
b. Upper valve of same.
White chalk of France

Fig. 281.



Radiolites foliaceus, D'Orb.
Syn. *Sphærulites agariciformis*, Blainv.
White chalk of France.

On the other hand, certain forms are common in the south which are rare or wholly unknown in the north of France.

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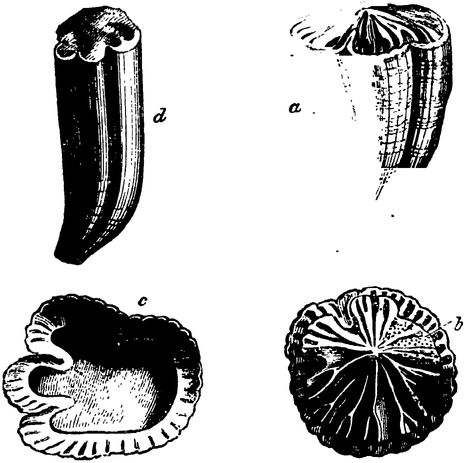
[1] D'Archiac, Sur la Form. Crétacée du S.-O. de la France, Mém. de la Soc. Géol. de France, tom. ii.

Among these may be mentioned many *Hippurites*, *Sphærulites*, and other members of that great order of mollusca called *Rudistes* by Lamarck, to which nothing analogous has been discovered in the living creation, but which is characteristic of rocks of the Cretaceous era in the south of France, Spain, Sicily, Greece, and other countries bordering the Mediterranean. The species called *Hippurites organisans* (fig. 282) is more abundant than any other in the south of Europe; and the geologist should make himself well acquainted with the cast of the interior *d*, which is often the only part preserved in many compact marbles of the Upper Cretaceous period. The flutings on the interior of the Hippurite, which are represented on the cast by smooth rounded longitudinal ribs and in some individuals attain a great size and length, are wholly unlike the markings on the exterior the shell.

Fig. 282.



Hippurites organisans, Desmoulins.
Upper chalk :—chalk marl of Pyrenees ?[1]

- *a*. Young individual; when full grown they occur in groups adhering laterally to each other.
- *b*. Upper side of the upper valve, showing a reticulated structure in those parts, *b*, where the external coating is worn off.
- *c*. Upper end or opening of the lower and cylindrical valve.
- *d*. Cast of the interior of the lower conical valve.

Cretaceous Rocks in the United States.—If we pass to the American continent, we find in the State of New Jersey a series of sandy and argillaceous beds wholly unlike in mineral character to our Upper Cretaceous system; which we can, nevertheless, recognise as referable, palæontologically, to the same division.

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[1] D'Orbigny's Paléontologie française, pl. 533.

That they were about the same age generally as the European chalk and Neocomian, was the conclusion to which Dr. Morton and Mr. Conrad came after their investigation of the fossils in 1834. The strata consist chiefly of greensand and green marl, with an overlying coral limestone of a pale yellow colour, and the fossils, on the whole, agree most nearly with those of the Upper European series, from the Maestricht beds to the Gault inclusive. I collected sixty shells from the New Jersey deposits in 1841, five of which were identical with European species—*Ostrea larva*, *O. vesicularis*, *Gryphæa costata*, *Pecten quinquecostatus*, *Belemnitella mucronata*. As some of these have the greatest vertical range in Europe, they might be expected more than any others to recur in distant parts of the globe. Even where the species were different, the generic forms, such as the Baculite and certain sections of Ammonites, as also the *Inoceramus* (see above, fig. 258, p. 278) and other bivalves, have a decidedly cretaceous aspect. Fifteen out of the sixty shells above alluded to were regarded by Professor Forbes as good geographical representatives of well-known cretaceous fossils of Europe. The correspondence, therefore, is not small, when we reflect that the part of the United States where these strata occur is between 3,000 and 4,000 miles distant from the chalk of Central and Northern Europe, and that there is a difference of ten degrees in the latitude of the places compared on opposite sides of the Atlantic. Fish of the genera *Lamna*, *Galeus*, and *Carcharodon* are common to New Jersey and the European cretaceous rocks. So also is the genus *Mosasaurus* among reptiles. Professor O. C. Marsh has described five species of birds from the greensand of New Jersey; and he has discovered in the Upper Cretaceous shale of Kansas a remarkable adult bird about the size of a pigeon, and probably aquatic, to which he gives the name of *Ichthyornis dispar*. This bird approaches the reptilian type in possessing biconcave vertebræ, and well-developed teeth in both jaws.[1]

It appears from the labours of Dr. Newberry and others, that the Cretaceous strata of the United States east and west of the Appalachians are characterised by a flora, decidedly analogous to that of Aix-la-Chapelle above-mentioned, and therefore having considerable resemblance to the vegetation of the Tertiary and Recent periods.

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[1] American Journ. of Science, vol. v., Feb. 1873.

CHAPTER XVIII.

LOWER CRETACEOUS OR NEOCOMIAN FORMATION.

Classification of marine and freshwater strata—Upper Neocomian—Folkestone and Hythe beds—Atherfield clay—Similarity of conditions causing reappearance of species after short intervals—Upper Speeton clay—Middle Neocomian—Tealby series—Middle Speeton clay—Lower Neocomian—Lower Speeton clay—Wealden formation—Freshwater character of the Wealden—Weald clay—Hastings sand—Punfield beds of Purbeck, Dorsetshire—Fossil shells and fish of the Wealden—Area of the Wealden—Flora of the Wealden.

We now come to the Lower Cretaceous formation which was formerly called Lower Greensand, and for which it will be useful for reasons before explained (p. 265) to use the term 'Neocomian.'

LOWER CRETACEOUS OR NEOCOMIAN GROUP.

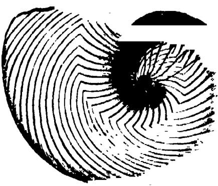
Marine.	Freshwater.
1. Upper Neocomian—Greensand of Folkestone, Sandgate and Hythe, Atherfield clay, upper part of Speeton clay.	Part of Wealden beds of Kent, Surrey, Sussex, Hants, and Dorset.
2. Middle Neocomian—Punfield marine bed, Tealby beds, middle part of Speeton clay.	
3. Lower Neocomian—Lower part of Speeton clay.	

In Western France, the Alps, the Carpathians, Northern Italy, and the Apennines, an extensive series of rocks has been described by Continental geologists under the name of Tithonian. These beds, which are without any marine equivalent in this country, appear completely to bridge over the interval between the Neocomian and the Oolites. They may, perhaps, as suggested by Mr. Judd, be of the same age as part of the Wealden series.

UPPER NEOCOMIAN.

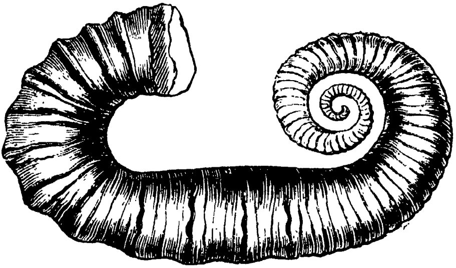
Folkestone and Hythe beds.—The sands which crop out beneath the Gault in Wiltshire, Surrey, and Sussex are sometimes in the uppermost part pure white, at others of a yellow and ferruginous colour, and some of the beds contain much green matter. At Folkestone they contain layers of calcareous matter and chert, and at Hythe, in the neighbourhood, as also at Maidstone and other parts of Kent, the limestone called Kentish Rag is intercalated. This somewhat clayey and calcareous stone forms strata two feet thick, alternating with quartzose sand. The total thickness of these Folkestone, Sandgate, and Hythe beds is less than 300 feet, and the Hythe beds are seen to rest immediately on a gray clay, to which we shall presently allude as the Atherfield clay. Among the fossils of the Hythe beds we may mention *Nautilus plicatus* (fig. 283), *Ancyloceras* (*Scaphites*) *gigas* (fig. 284), which has been aptly described as an Ammonite more or less uncoiled; *Trigonia caudata* (fig. 286), *Gervillia anceps* (fig. 285), a bivalve genus allied to Avicula, and *Terebratula sella* (fig. 287). In ferruginous beds of the same age in Wiltshire is found the remarkable shell called *Diceras Lonsdalii* (fig. 288, p. 294), which abounds in the Upper and Middle Neocomian of Southern Europe. This genus is closely allied to Chama, and the cast of the interior has been compared to the horns of a goat.

Fig. 283.



Nautilus plicatus, Sow., in Fitton's Monog.

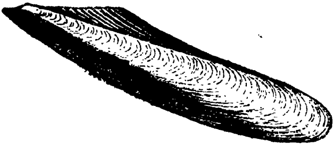
Fig. 284.



Ancyloceras gigas, D'Orb.

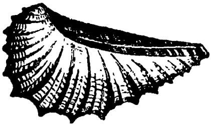
Atherfield Clay.—We mentioned before that the Hythe series rests on a gray clay. This clay is only of slight thickness in Kent and Surrey, but acquires great dimensions at Atherfield in the Isle of Wight. The difference indeed in mineral character and thickness of the Upper Neocomian formation near Folkestone, and the corresponding beds in the south of the Isle of Wight, about 100 miles distant, is truly remarkable. In the latter place we find no limestone answering to the Kentish Rag, and the entire thickness from the bottom of the Atherfield clay to the top of the Neocomian, instead of being less than 300 feet as in Kent, is given by the late Professor E. Forbes as 843 feet, which he divides into sixty-three strata, forming three groups. The uppermost of these consists of ferruginous sands ; the second of sands and clay ; and the third or lowest of a brown clay, abounding in fossils.

Fig. 285.



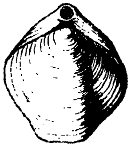
Gervillia anceps, Desh.
Upper Neocomian, Surrey.

Fig. 286.



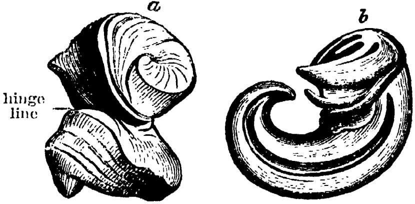
Trigonia caudata, Agass.
Upper Neocomian.

Fig. 287.



Terebratula sella, Sow.
Upper Neocomian, Hythe.

Fig. 288.



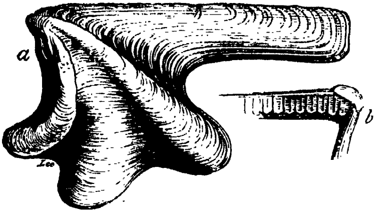
Diceras Lonsdalii. Upper Neocomian, Wilts.
a. The bivalve shell.
b. Cast of one of the valves enlarged.

Pebbles of quartzose sandstone, jasper, and flinty slate, together with grains of chlorite and mica, occur ; and fragments and waterworn fossils of the oolitic rocks speak plainly, as Mr. Godwin-Austen has shown, of the nature of the pre-existing formations, by the wearing down of which the Neocomian beds were formed. The land, consisting of such rocks, was doubtless submerged before the origin of the white chalk, a deposit which was formed in a more open and probably deeper sea, and in clearer waters.

Among the shells of the Atherfield clay the most abundant is the large *Perna Mulleti*, of which a reduced figure is here given (fig. 289).

Similarity of conditions causing reappearance of species.—Some species of mollusca and other fossils range through the whole series, while others are confined to particular subdivisions, and Forbes laid down a law which has since been found of very general application in regard to estimating the chronological relations of consecutive strata. Whenever similar conditions, he says, are repeated, the same species reappear, provided too great a lapse of time has not intervened ; whereas if the length of the interval has been geologically great, the same genera will reappear represented by distinct species. Changes of depth, or of the mineral nature of the sea-bottom, the presence or absence of lime or of peroxide of iron, the occurrence of a muddy, or a sandy, or a gravelly bottom, are marked by the banishment of certain species and the predominance of others. But these differences of conditions, being mineral, chemical, and local in their nature, have no necessary connection with the extinction, throughout a large area, of certain animals or plants. When the forms proper to loose sand or soft clay, or to perfectly clear water, or to a sea of moderate or great depth, recur with all the same species, we may infer that the interval of time has been, geologically speaking, small, however dense the mass of matter accumulated. But if, the genera remaining the same, the species are changed, we have entered upon a new period; and no similarity of climate, or of geographical and local conditions, can then recall the old species which a long series of destructive causes in the animate and inanimate world has gradually annihilated.

Fig. 289.



Perna Mulleti, Desh.
¼ nat. size.
a. Exterior.
b. Part of hinge-line of upper or right valve.

Speeton Clay, upper division.—On the coast beneath the white chalk of Flamborough Head, in Yorkshire, an argillaceous formation crops out, called the Speeton clay, several hundred feet in thickness, the palæontological relations of which have been ably worked out by Mr. John W. Judd;[1] and he has shown that it is separable into three divisions, the uppermost of which, 150 feet thick, and containing 87 species of mollusca, decidedly belongs to the Atherfield clay and associated strata of Hythe and Folkestone, already described. It is characterised by the *Perna Mulleti* (fig. 289) and *Terebratula sella* (fig. 287), and by *Ammonites Deshayesii* (fig. 290), a well-known Hythe and Atherfield fossil. Fine skeletons of reptiles of the genera Pliosaurus and Teleosaurus have been obtained from this clay. At the base of this upper division of the Speeton clay there occurs a layer of large Septaria, formerly worked for the manufacture of cement. This bed is crowded with fossils, especially Ammonites, one species of which, three feet in diameter, was observed by Mr. Judd.

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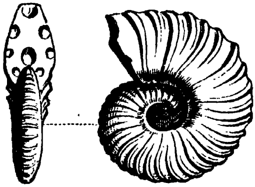
[1] Judd, Speeton Clay, Quart. Geol. Journ. vol. xxiv. 1868, p. 218.

Fig. 290.

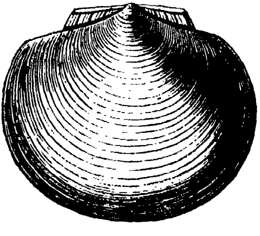


Ammonites Deshayesii, Leym. Upper Neocomian.

MIDDLE NEOCOMIAN.

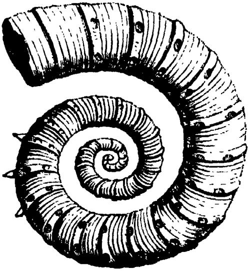
Tealby series.—At Tealby, a village in the Lincolnshire Wolds, there crops out beneath the white chalk some non-fossiliferous ferruginous sands about twenty feet thick, beneath which are beds of clay and limestone about fifty feet thick, with an interesting suite of fossils, among which are *Pecten cinctus* (fig. 291), from 9 to 12 inches in diameter, *Ancyloceras Duvallii* (fig. 292), and some 40 other shells, many of them common to the Middle Speeton clay, about to be mentioned. Mr. Judd remarks that as *Ammonites clypeiformis* and *Terebratula hippopus* characterise the Middle Neocomian of the Continent, it is to this stage

Fig. 291.



Pecten cinctus, Sow. (*P. crassitesta*, Röm.) Middle Neocomian, England; Middle and Lower Neocomian, Germany. ⅛ nat. size.

Fig. 292.



Ancyloceras (Crioceras) *Duvallii*, Leveillé. Middle and Lower Neocomian, ⅛ nat. size.

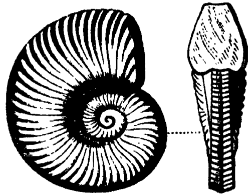
that the Tealby series containing the same fossils may be assigned.[1]

The middle division of the Speeton clay, occurring at Speeton below the cement-bed, before alluded to, is 150 feet thick and contains about 39 species of mollusca, half of which are common to the overlying clay. Among the peculiar shells, as before mentioned, *Ancyloceras* (*Crioceras*) *Duvallii* (fig. 292) and *Pecten cinctus* (fig. 291) occur.

LOWER NEOCOMIAN.

In the lower division of the Speeton clay, 200 feet thick, 46 species of mollusca have been found, and three divisions, each characterised by its peculiar ammonite, have been noticed by Mr. Judd. The central zone is marked by *Ammonites Noricus* (see fig. 293). On the Continent these beds are well known by their corresponding fossils, the Hils clay and conglomerate of the north of Germany agreeing with the Middle and Lower Speeton, the latter of which, with the same mineral characters and fossils as in Yorkshire, is also found in the little island of Heligoland. Yellow limestone, which I have myself seen near Neuchâtel, in Switzerland, represents the lower Neocomian at Speeton.

Fig. 293.



Ammonites Noricus, Schloth.
Lower Neocomian. Speeton.

WEALDEN FORMATION.

Beneath the Atherfield clay or Upper Neocomian of the S.E. of England, a freshwater formation is found, called the Wealden, which, although it occupies a small horizontal area in Europe, as compared to the White Chalk and the marine Neocomian beds, is nevertheless of great geological interest, since the imbedded remains give us some insight into the nature of the terrestrial fauna and flora of the Lower Cretaceous epoch. The name of Wealden was given to this group because it was first studied in parts of Kent, Surrey, and Sussex, called the Weald; and we are indebted to Dr. Mantell for having shown, in 1822, in his 'Geology of Sussex,' that the whole group was of fluviatile origin. In proof of this he called attention to the entire absence of Ammonites, Belemnites, Brachiopoda, Echinodermata, Corals, and other marine fossils, so characteristic of the Cretaceous rocks above, and of the Oolitic strata below, and to the presence in the Weald of Paludinæ, Melaniæ, Cyrenæ, and various fluviatile shells, as well as the bones of terrestrial reptiles and the trunks and leaves of land-plants.

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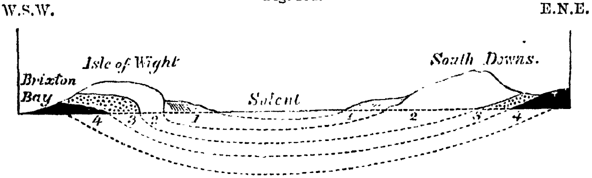
[1] Judd, Quart. Geol. Journ. 1867, vol. xxiii. p. 249.

The evidence of so unexpected a fact as that of a dense mass of purely freshwater origin underlying a deep-sea deposit (a phenomenon with which we have since become familiar) was received, at first, with no small doubt and incredulity. But the relative position of the beds is unequivocal; the Weald clay being distinctly seen to pass beneath the Atherfield clay in various parts of Surrey, Kent, and Sussex, and to reappear in the Isle of Wight at the base of the Cretaceous series, being, no doubt, continuous far beneath the surface, as indicated by the dotted lines in the annexed diagram (fig. 294). They are also found occupying the same relative position below the chalk in the peninsula of Purbeck, where, as we shall see in the sequel, they repose on strata referable to the Upper Oolite.

Fig. 294.



1. Tertiary. 2. Chalk and Gault. 3. Upper Neocomian (or Lower Greensand). 4. Wealden (Weald Clay and Hastings Sand).

Weald Clay.—The upper division, or Weald clay, is, in great part, of freshwater origin, but in its highest portion contains beds of oysters and other marine shells which indicate fluvio-marine conditions. The uppermost beds are not only conformable, as Dr. Fitton observes, to the inferior strata of the overlying Neocomian, but of similar mineral composition. To explain this, we may suppose, that, as the delta of a great river was tranquilly subsiding, so as to allow the sea to encroach upon the space previously occupied by fresh water, the river still continued to carry down the same sediment into the sea. In confirmation of this view it may be stated that the remains of the *Iguanodon Mantelli*, a gigantic terrestrial reptile, belonging to the order Dinosauria, and very characteristic of the Wealden, has been discovered near Maidstone, in the overlying Kentish rag, or marine limestone of the Upper Neocomian. Hence we may infer that some of the saurians which inhabited the country of the great river continued to live when part of the district had become submerged beneath the sea. Thus, in our own times, we may suppose the bones of large alligators to be frequently entombed in recent freshwater strata in the delta of the Ganges. But if part of that delta should sink down so as to be covered by the sea, marine formations might begin to accumulate in the same space where freshwater beds had previously been formed; and yet the Ganges might still pour down its turbid waters in the same direction, and carry seaward the carcases of the same species of alligator, in which case their bones might be included in marine as well as in subjacent freshwater strata.

The Iguanodon, first discovered by Dr. Mantell, was an herbivorous reptile, of which the teeth, though bearing a great analogy, in their general form and crenated edges (see figs. 295, *a*, 295, *b*), to the modern Iguanas which now frequent the tropical woods of America and the West Indies, exhibit many important differences. It appears that they have often been worn by the process of mastication; whereas the existing herbivorous reptiles clip and gnaw off the vegetable productions on which they feed, but do not chew them. Their teeth frequently present an appearance of having been chipped off, but never, like the fossil teeth of the Iguanodon, have a flat ground surface (see fig. 296, *b*) resembling the grinders of herbivorous mammalia. Dr. Mantell computes that the teeth and bones of this species, which passed under his examination during twenty years, must have belonged to no less than seventy-one distinct individuals,

Fig. 295.

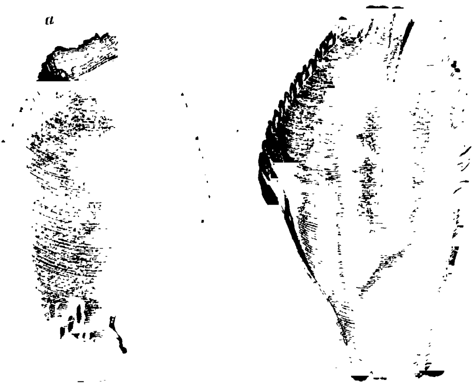


Fig. 296.

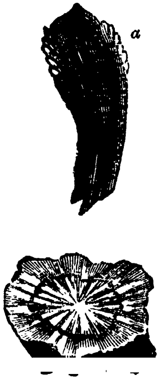
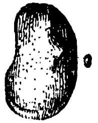


Fig. 295. *a*, *b*. Tooth of *Iguanodon Mantelli*.
296. *a*. Partially worn tooth of young individual of the same.
b. Crown of tooth in adult, worn down. (Mantell.)

varying in age and magnitude from the reptile just burst from the egg, to one of which the femur measured twenty-four inches in circumference. Yet, notwithstanding that the teeth were more numerous than any other bones, it is remarkable that it was not until the relics of all these individuals had been found, that a solitary example of part of a jawbone was obtained. Soon afterwards remains both of the upper and lower jaw were met with in the Hastings beds in Tilgate Forest near Cuckfield. In the same sands at Hastings, Mr. Beckles found large tridactyle impressions which it is conjectured were made by the hind feet of this animal, on which it is ascertained that there were only three well-developed toes.

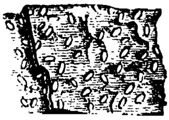
Occasionally bands of limestones called Sussex Marble, occur in the Weald clay, almost entirely composed of a species of *Paludina*, closely resembling the common *P. vivipara* of English rivers. Shells of the *Cypris*, a genus of Crustaceans before mentioned (p. 33), as abounding in lakes and ponds, are also plentifully scattered through the clays of the Wealden, sometimes producing, like plates of mica, a thin lamination (see fig. 298).

Fig. 297.



Cypris spinigera, Fitton.

Fig. 298.



Weald clay with Cyprides.

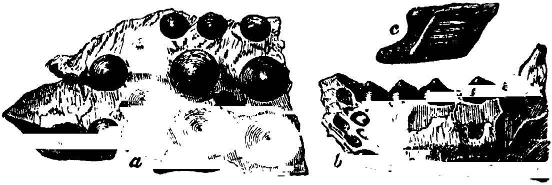
Hastings Sands.—This lower division of the Wealden consists of sand, sandstone, calciferous grit, clay, and shale ; the argillaceous strata, notwithstanding the name, predominating somewhat over the arenaceous, as will be seen by reference to the following section, drawn up by Messrs. Drew and Foster, of the Geological Survey of Great Britain :—

	Names of Subordinate Formations.	Mineral Composition of the Strata.	Thickness in Feet.
Hastings Sand.	Tunbridge Wells Sand . .	Sandstone and loam. .	150
	Wadhurst Clay	Blue and brown shale and clay with a little calc-grit	100
	Ashdown Sand	Hard sand with some beds of calc-grit . . .	160
	Ashburnham Beds	Mottled white and red clay with some sandstone .	330

The picturesque scenery of the 'High Rocks' and other places in the neighbourhood of Tunbridge Wells, is caused by the steep natural cliffs, to which a hard bed of white sand, *occurring in* the upper part of the Tunbridge Wells Sand, mentioned in the above table, gives rise. This bed of 'rock sand' varies in thickness from 25 to 48 feet. Large masses of it, which were by no means hard or capable of making a good building-stone, form, nevertheless, projecting rocks with perpendicular faces, and resist the degrading action of the river because, says Mr. Drew, they present a solid mass without planes of division. The calcareous sandstone and grit of Tilgate Forest, near Cuckfield, in which the remains of the Iguanodon and Hylæosaurus were first found by Dr. Mantell, constitute an upper member of the Tunbridge Wells Sand, while the 'sand rock' of the Hastings cliffs, about 100 feet thick, is one of the lower members of the same. The reptiles, which are very abundant in this division, consist partly of saurians, referred by Owen and Mantell to eight genera, among which, besides those already enumerated, we find the Megalosaurus and Plesiosaurus. The Pterodactyl also, a flying reptile, is met with in the same strata, and many remains of Chelonians of the genera *Trionyx* and *Emys*, now confined to tropical regions.

The fishes of the Wealden are chiefly referable to the Ganoid and Placoid orders. Among them the teeth and scales of *Lepidotus* are most widely diffused (see fig. 299). These ganoids were allied to the *Lepidosteus*, or Gar-pike, of the American rivers. The whole body was covered with large and very thick rhomboidal scales, having the exposed part coated with enamel. Most of the species of this genus are supposed to have been either river-fish, or inhabitants of the sea at the mouth of estuaries.

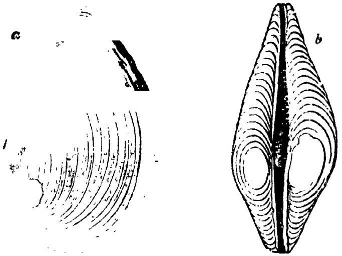
Fig. 299.



Lepidotus Mantelli, Agass. Wealden.
a. Palate and teeth. *b.* Side view of teeth. *c.* Scale.

At different horizons in the Hastings Sand, we find again and again slabs of sandstone with a strong ripple-mark, and between these slabs beds of clay many yards thick. In some places, as at Stammerham, near Horsham, there are indications of this clay

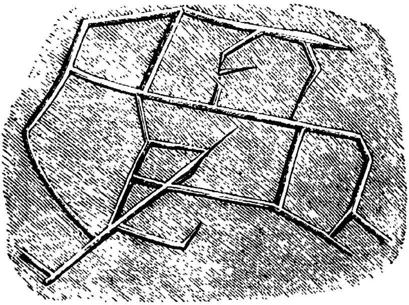
Fig. 300.



Unio Valdensis, Mant.
Isle of Wight and Dorsetshire; in the lower beds of the Hastings Sands.

having been exposed so as to dry and crack before the next layer was thrown down upon it. The open cracks in the clay have served as moulds, of which casts have been taken in relief, and which are, therefore, seen on the lower surface of the sandstone (see fig. 301).

Fig. 301.



Underside of slab of sandstone about one yard in diameter. Stammerham, Sussex.

Near the same place a reddish sandstone occurs in which are innumerable traces of a fossil vegetable, apparently *Sphenopteris*, the stems and branches of which are disposed as if the plants were standing erect on the spot where they originally grew, the sand having been gently deposited upon and around them; and similar appearances have been remarked in other places in this formation.[1] In the same division also of the Wealden, at Cuckfield, is a bed of gravel or conglomerate, consisting of waterworn pebbles of quartz and jasper, with rolled bones of reptiles. These must have been drifted by a current, probably in water of no great depth.

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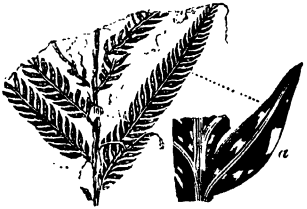
[1] Mantell, Geol. of S.E. of England, p. 244.

Fig. 302.

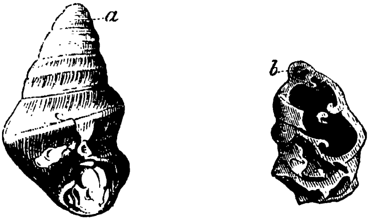


Sphenopteris gracilis, Fitton. From the Hastings Sands near Tunbridge Wells.
a. Portion of the same magnified.

From such facts we may infer that, notwithstanding the great thickness of this division of the Wealden, the whole of it was a deposit in water of a moderate depth, and often extremely shallow. This idea may seem startling at first, yet such would be the natural consequence of a gradual and continuous sinking of the ground in an estuary or bay, into which a great river discharged its turbid waters. By each foot of subsidence, the fundamental rock would be depressed one foot farther from the surface ; but the bay would not be deepened, if newly deposited mud and sand should raise the bottom one foot. On the contrary, such new strata of sand and mud might be frequently laid dry at low water, or overgrown for a season by a vegetation proper to marshes.

Punfield beds, brackish and marine.—The shells of the Wealden beds belong to the genera *Melanopsis*, *Melania*, *Paludina*, *Cyrena*, *Cyclas*, *Unio* (see fig. 300), and others, which inhabit estuaries, rivers, or lakes ; but one band has been found at Punfield, in Dorsetshire, indicating a brackish state of the water, where the genera *Corbula*, *Mytilus*, and *Ostrea* occur ;

Fig. 303.



Vicarya Lujani, De Verneuil,[1] Wealden, Punfield.
a. Nearly perfect shell.
b. Vertical section of smaller specimen, showing continuous ridges as in *Nerinæa*.

and in some places this bed becomes purely marine, containing some well-known Neocomian fossils, among which *Ammonites*

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[1] Foss. de Utrillas.

Deshayesii (fig. 290, p. 296) may be mentioned. Others are peculiar as British, but very characteristic of the Upper and Middle Neocomian of the north of Spain, and among these is conspicuous the *Vicarya Lujani* (fig. 303), a shell allied to Nerinæa. The middle Neocomian beds of Spain in which this shell abounds, attain at Utrillas a thickness of 530 feet, and contain ten beds of coal, lignite or jet, which are extensively worked.[1]

By reference to the table (p. 292) it will be seen that the Wealden beds are given as the freshwater equivalents of the Marine Neocomian. The highest part of them in England may, for reasons just given, be regarded as Upper Neocomian, while some of the inferior portions may correspond in age to the Middle and Lower divisions of that group. In favour of this latter view, M. Marcou mentions that a fish called *Asteracanthus granulosus*, occurring in the Tilgate beds, is characteristic of the lowest beds of the Neocomian of the Jura, and it is well known that *Corbula alata*, common in the Ashburnham beds, is found also at the base of the Neocomian of the Continent.

Area of the Wealden.—In regard to the geographical extent of the Wealden, it cannot be accurately laid down; because so much of it is concealed beneath the newer marine formations. It has been traced about 320 English miles from west to east, from the coast of Dorsetshire to near Boulogne, in France; and nearly 200 miles from north-west to south-east, from Surrey and Hampshire to Vassy, in France. If the formation be continuous throughout this space, which is very doubtful, it does not follow that the whole was contemporaneous; because, in all likelihood, the physical geography of the region underwent frequent changes throughout the whole period, and the estuary may have altered its form, and even shifted its place. Dr. Dunker, of Cassel, and H. von Meyer, in an excellent monograph on the Wealdens of Hanover and Westphalia, have shown that they correspond so closely, not only in their fossils, but also in their mineral characters, with the English series, that we can scarcely hesitate to refer the whole to one great delta. Even then, the magnitude of the deposit may not exceed that of many modern rivers. Thus, the delta of the Quorra or Niger, in Africa, stretches into the interior for more than 170 miles, and occupies, it is supposed, a space of more than 300 miles along the coast, thus forming a surface of more than 25,000 square miles, or equal to about one half of England.[2] Besides, we know not, in such cases, how far the fluviatile sediment and organic remains of the river and the land may be carried out from the coast, and spread over the bed of the sea. I have shown, when treating of the Mississippi, that a more ancient delta, including species of shells such as now inhabit Louisiana, has been upraised, and made to occupy a wide geographical area, while a newer delta is forming;[1] and the possibility of such movements and their effects must not be lost sight of when we speculate on the origin of the Wealden.

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[1] Judd, Quart. Geol. Journ. vol. xxvii. 1871, p. 225.

[2] Fitton, Geol. of Hastings, p. 58, who cites Lander's Travel.

It may be asked where the continent was placed, from the ruins of which the Wealden strata were derived, and by the drainage of which a great river was fed. If the Wealden were gradually going downwards 1,000 feet or more perpendicularly, a large body of fresh water would not continue to be poured into the sea at the same point. The adjoining land, if it participated in the movement, could not escape being submerged. But we may suppose such land to have been stationary, or even undergoing contemporaneous slow upheaval. There may have been an ascending movement in one region, and a descending one in a contiguous parallel zone of country. But, even if that were the case, it is clear that finally an extensive depression took place in that part of Europe where the deep sea of the Cretaceous period was afterwards brought in.

Thickness of the Wealden.—In the Weald area itself, between the North and South Downs, freshwater beds to the thickness of 1,600 feet are known, the base not being reached. Probably the thickness of the whole Wealden series, as seen in Swanage Bay, cannot be estimated as less than 2,000 feet.

Wealden Flora.—The flora of the Wealden is characterised by a great abundance of Coniferæ, Cycadeæ, and Ferns, and by the absence of leaves and fruits of dicotyledonous angiosperms. The discovery in 1855, in the Hastings beds of the Isle of Wight, of Gyrogonites, or spore-vessels of the Chara, was the first example of that genus of plants so common in the Tertiary strata, being found in a Secondary or Mesozoic rock.

Lower Cretaceous Arctic flora.—A remarkable counterpart to this Lower Neocomian flora has been lately (1872) brought by Professor Nordenskiöld from Greenland, lat. 71° N., and Spitzbergen, lat. 78° N., the species having been determined by Professor Heer. The Greenland plants, among which are eight species of Cycads and 35 species of Ferns, agree very closely with the flora of the Lower Chalk of Europe, and have a decidedly sub-tropical aspect. Professor Heer mentions 13 species of Gleichenia, many of them retaining even the fruit; and this genus is now almost exclusively tropical, although represented by a few rare species in New Zealand and Tasmania. Other sub-tropical forms, such as Oleander, are also present. Among the Spitzbergen plants, which are less numerous, the Sequoia Reichenbachii, common to the Lower Cretaceous of Greenland, is very abundant, one branch bearing the fruit. We cannot therefore doubt that the warm climate of the Cretaceous period extended to within 12° of the pole, though in the present state of our knowledge we are quite unable to frame any satisfactory theory as to the causes by which it was produced.

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[1] See above, p. 79; and Second Visit to the U. S., vol. ii. chap. xxxiv.

CHAPTER XIX.

JURASSIC GROUP.—PURBECK BEDS AND OOLITE.

The Purbeck beds a member of the Jurassic group—Subdivisions of that group—Physical geography of the Oolite in England and France—Upper Oolite—Purbeck beds—New genera of fossil mammalia in the Middle Purbeck of Dorsetshire—Dirt-bed or ancient soil—Fossils of the Purbeck beds—Portland stone and fossils—Kimmeridge clay—Lithographic stone of Solenhofen—Archæopteryx—Middle Oolite—Coral rag—Nerinæa limestone—Oxford Clay, Ammonites and Belemnites—Kelloway Rock—Lower, or Bath Oolite—Great plants of the Oolite—Oolite and Bradford clay—Stonesfield slate—Fossil mammalia—Fuller's earth—Inferior Oolite and fossils—Northamptonshire slates—Yorkshire Oolitic coal-field—Brora coal—Palæontological relations of the several subdivisions of the Oolitic group.

Classification of the Oolite.—Immediately below the Hastings Sands we find in Dorsetshire another remarkable freshwater formation, called *the Purbeck* because it was first studied in the sea-cliffs of the Peninsula of Purbeck in that county. These beds are for the most part of freshwater origin; but the organic remains of some few intercalated beds are marine, and show that the Purbeck series has a closer affinity to the Oolitic group, of which it may be considered as the newest or uppermost member.

In England generally, and in the greater part of Europe, both the Wealden and Purbeck beds are wanting, and the marine Cretaceous group is followed immediately, in the descending order, by another series called the Jurassic. In this term, the formations commonly designated as 'the Oolite and Lias' are included, both being found in the Jura Mountains. The Oolite was so named because, in the countries where it was first examined, the limestones belonging to it had an Oolitic structure (see p. 13). These rocks occupy in England a zone nearly thirty miles in average breadth, which extends across the island, from Yorkshire in the north-east, to Dorsetshire in the south-west. Their mineral characters are not uniform throughout this region; but the following are the names of the principal subdivisions observed in the central and south-eastern parts of England:—

OOLITE.

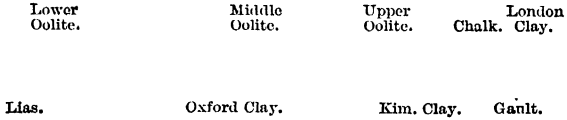
Upper	*a.*	Purbeck beds.
	b.	Portland oolite (stone) and sand.
	c.	Kimmeridge clay.
Middle	*d.*	Coral rag.
	e.	Oxford clay, and Kelloway rock.
Lower	*f.*	Cornbrash and Forest marble.
	g.	Great Oolite and Stonesfield slate.
	h.	Fuller's earth.
	i.	Inferior Oolite.

The Upper Oolitic system of the above table has usually the Kimmeridge clay for its base; the Middle Oolitic system, the Oxford clay. The Lower system reposes on the Lias, an argillo-calcareous formation, which some include in the Lower Oolite, but which will be treated of separately in the next chapter. Many of these subdivisions are distinguished by peculiar organic remains; and, though varying in thickness, may be traced in certain directions for great distances, especially if we compare the part of England to which the above-mentioned type refers with the north-east of France and the Jura Mountains adjoining. In that country, distant above 400 geographical miles, the analogy to the accepted English type, notwithstanding the thinness or occasional absence of the clays, is more perfect than in Yorkshire or Normandy.

Physical Geography.—The alternation, on a grand scale, of distinct formations of clay and limestone has caused the oolitic and liassic series to give rise to some marked features in the physical outline of parts of England and France. Wide valleys can usually be traced throughout the long bands of country where the argillaceous strata crop out; and between these valleys the limestones are observed, forming ranges of hills or more elevated grounds. These ranges terminate abruptly on the side on which the several clays rise up from beneath the calcareous strata.

The annexed cut will give the reader an idea of the configuration of the surface now alluded to, such as may be seen in

Fig. 304.



passing from London to Cheltenham, or in other parallel lines, from east to west, in the southern part of England. It has been necessary, however, in this drawing, greatly to exaggerate the inclination of the beds, and the height of the several formations, as compared to their horizontal extent. It will be remarked, that the lines of steep slope, or escarpment, face towards the west in the great calcareous eminences formed by the Chalk and the Upper, Middle, and Lower Oolites; and at the base of which we have respectively the Gault, Kimmeridge clay, Oxford clay, and Lias. This last forms, generally, a broad vale at the foot of the escarpment of inferior Oolite; but where it acquires considerable thickness, and contains solid beds of marlstone, it occupies the lower part of the escarpment.

The external outline of the country which the geologist observes in travelling eastward from Paris to Metz, is precisely analogous, and is caused by a similar succession of rocks intervening between the tertiary strata and the Lias; with this difference, however, that the escarpments of Chalk, and Upper, Middle, and Lower Oolites face towards the east instead of the west. It is evident, therefore, that the denuding causes (see p. 81) have acted similarly over an area several hundred miles in diameter, removing the softer clays more extensively than the limestones, and causing these last to form steep slopes or escarpments wherever the harder calcareous rock was based upon a more yielding and destructible formation.

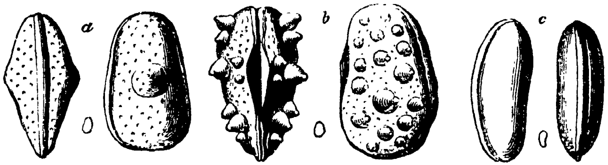
UPPER OOLITE.

Purbeck beds.—These strata, which we class as the uppermost member of the Oolite, are of limited geographical extent in Europe, as already stated, but they acquire importance when we consider the succession of three distinct sets of fossil remains which they contain. Such repeated changes in organic life must have reference to the history of a vast lapse of ages. The Purbeck beds are finely exposed to view in Durdlestone Bay, near Swanage, Dorsetshire, and at Lulworth Cove and the neighbouring bays between Weymouth and Swanage. At Meup's Bay, in particular, Professor E. Forbes examined minutely, in 1850, the organic remains of this group, displayed in a continuous sea-cliff section; and it appears from his researches that the Upper, Middle, and Lower Purbecks are each marked by peculiar species of organic remains, these again being different, so far as a comparison has yet been instituted, from the fossils of the overlying Hastings Sands and Weald Clay.

Upper Purbeck.—The highest of the three divisions is purely freshwater, the strata, about fifty feet in thickness, containing shells of the genera *Paludina, Physa, Limnæa, Planorbis, Val-*

vata, *Cyclas*, and *Unio*, with *Cyprides* and fish. All the species seem peculiar, and among these the *Cyprides* are very abundant and characteristic. (See fig. 305, *a*, *b*, *c*.)

Fig. 305.

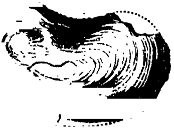


Cyprides from the Upper Purbecks.
a. *Cypris gibbosa*, E. Forbes. *b*. *Cypris tuberculata*, E. Forbes.
c. *Cypris leguminella*, E. Forbes.

The stone called 'Purbeck Marble,' formerly much used in ornamental architecture in the old English cathedrals of the southern counties, is exclusively procured from this division.

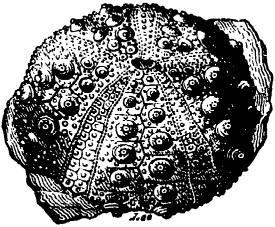
Middle Purbeck.—Next in succession is the Middle Purbeck, about thirty feet thick, the uppermost part of which consists of freshwater limestone, with cyprides, turtles, and fish of different species from those in the preceding strata. Below the limestone are brackish-water beds full of *Cyrena*, and traversed by bands abounding in *Corbula Melania.* These are based on a purely marine deposit, with *Pecten*, *Modiola*, *Avicula*, and *Thracia.* Below this, again, come limestones and shales, partly of brackish and partly of freshwater origin, in which many fish, especially species of *Lepidotus* and *Microdon radiatus*, are found, and a crocodilian reptile named *Macrorhynchus.* Among the mollusks, a remarkable ribbed *Melania*, of the subgenus *Chilina*, occurs.

Fig. 306.



Ostrea distorta, Sow.
Cinder-bed, Middle Purbeck.

Fig. 307.

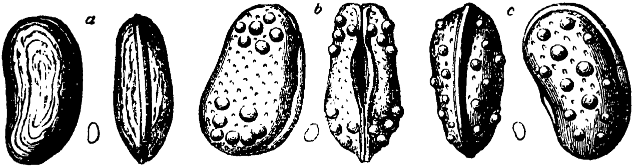


Hemicidaris Purbeckensis, E. Forbes.
Middle Purbeck.

Immediately below is a great and conspicuous stratum, twelve feet thick, formed of a vast accumulation of shells of

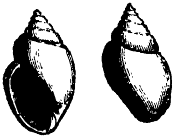
Ostrea distorta (fig. 306), long familiar to geologists under the local name of 'Cinder-bed.' In the uppermost part of this bed Professor Forbes discovered the first echinoderm (fig. 307) as yet known in the Purbeck series, a species of *Hemicidaris*, a genus characteristic of the Oolitic period, and scarcely, if at all, distinguishable from a previously known Oolitic fossil. It was accompanied by a species of *Perna*. Below the Cinder-bed freshwater strata are again seen, filled in many places with species of *Cypris* (fig. 308, *a*, *b*, *c*), and with *Valvata*, *Paludina*, *Planorbis*, *Limnæa*, *Physa* (fig. 309), and *Cyclas*, all different from any occurring higher in the series. It will be seen that *Cypris fasciculata* (fig. 308, *b*) has tubercles at the end only of each valve, a character by which it can be immediately recognised. In fact, these minute crustaceans, almost as frequent in some of the shales as plates of mica in a micaceous sandstone, enable geologists at once to identify the Middle Purbeck in places far from the Dorsetshire cliffs, as for example, in the Vale of Wardour, in Wiltshire. Thick beds of chert occur in the Middle Purbeck filled with mollusca and cyprides of the genera already enumerated, in a beautiful state of preservation, often converted into chalcedony. Among these Professor Forbes met with gyrogonites (the spore-vessels of *Chara*), plants never before discovered in rocks older than the Eocene. About twenty feet below the 'Cinder-bed' is a stratum two or three inches thick, in which fossil mammalia presently to be mentioned occur; and beneath this a thin band of greenish shales, with marine shells and impressions of leaves like those of a large *Zostera*, forming the base of the Middle Purbeck.

Fig. 308.



Cyprides from the Middle Purbecks.
a. *Cypris striato-punctata*, E. Forbes. *b*. *Cypris fasciculata*, E. Forbes.
c. *Cypris granulata*, Sow.

Fig. 309.



Physa Bristovii, E. Forbes. Middle Purbeck.

Fossil Mammalia of the Middle Purbeck.—In 1852,[1] after alluding to the discovery of numerous insects and air-breathing mollusca in the Purbeck strata, I remarked that, although no mammalia had then been found, 'it was too soon to infer their non-existence on mere negative evidence.' Only two years after this remark was in print, Mr. W. R. Brodie found in the Middle Purbeck, about twenty feet below the 'Cinder-bed' above alluded to, in Durdlestone Bay, portions of several small jaws with teeth, which Professor Owen recognised as belonging to a small mammifer of the insectivorous class, more closely allied in its dentition to the *Amphitherium* (or *Thylacotherium*) than to any existing type.

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[1] Elements of Geology, 4th edition.

Two years later (in 1856) the remains of several other species of warm-blooded quadrupeds were exhumed by Mr. S. H. Beckles, F.R.S., from the same thin bed of marl near the base of the Middle Purbeck. In this marly stratum many reptiles, several insects, and some freshwater shells of the genera *Paludina*, *Planorbis*, and *Cyclas* were found.

Mr. Beckles has thoroughly explored the thin layer of calcareous mud from which in the suburbs of Swanage the bones of the Spalacotherium had already been obtained, and he has brought to light from an area forty feet long and ten wide, and from a layer the average thickness of which was only five inches, portions of the skeletons of six new species of mammalia, as interpreted by Dr. Falconer, who first examined them. Before these interesting enquiries were brought to a close, the joint labours of Professor Owen and Dr. Falconer had made it clear that twelve or more species of mammalia characterised this portion of the Middle Purbeck, most of them insectivorous or predaceous, varying in size from that of a mole to that of the common polecat, *Mustela putorius*; and Professor Owen has subsequently raised the number of species to twenty-five, referable to ten genera.[1] While the majority had the character of insectivorous marsupials, Dr. Falconer selected one as differing widely from the rest, and pointed out that in certain characters it was allied to the living Kangaroo-rat, or *Hypsiprymnus*, ten species of which now inhabit the prairies and scrub-jungle of Australia, feeding on plants and gnawing scratched-up roots. A striking peculiarity of their dentition, one in which they differ from all other quadrupeds, consists in their having a single large pre-molar, the enamel of which is furrowed with vertical grooves, usually seven in number.

The largest pre-molar (see fig. 311) in the fossil genus exhibits in like manner seven parallel grooves, producing by their termination a similar serrated edge in the crown; but their direction is diagonal—a distinction, says Dr. Falconer, which is 'trivial, not typical.' As these oblique furrows form so marked a character of the majority of the teeth, Dr. Falconer gave to the fossil the generic name of *Plagiaulax*. The shape and relative size of the incisor *a*, fig. 312, exhibit a no less striking similarity to *Hypsiprymnus*. Nevertheless, the more sudden upward curve of this incisor, as well as other characters of the jaw, indicate a great deviation in the form of *Plagiaulax* from that of the living kangaroo-rats.

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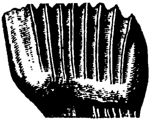
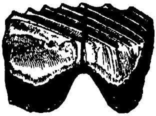
[1] Monograph, Paleontological Society, 1871.

Fig. 310.



Pre-molar of the recent Australian Hypsiprymnus Gaimardi, showing 7 grooves, at right angles to the length of the jaw, magnified 3½ diameters.

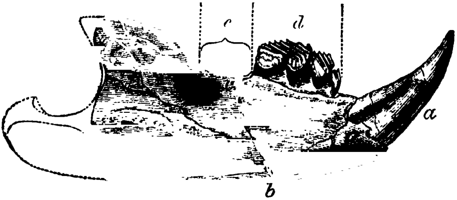
Fig. 311.



Third and largest pre-molar (lower jaw) of *Plagiaulax Becklesii*, magnified 5½ diameters, showing 7 diagonal grooves.

There are two fossil specimens of lower jaws of this genus evidently referable to two distinct species extremely unequal in size and otherwise distinguishable. The *Plagiaulax Becklesii* (fig. 312) was about as big as the English squirrel or the flying phalanger of Australia (*Petaurus Australis*, Waterhouse). The smaller fossil, having only half the linear dimensions of the other, was probably only 1-12th of its bulk. It is of peculiar geological interest, because, as shown by Dr. Falconer, its two back molars bear a decided resemblance to those of the Triassic *Microlestes* (fig. 396, p. 356), the most ancient of known mammalia, of which an account will be given in Chapter XXI.

Fig. 312.



Plagiaulax Becklesii, Falconer. Middle Purbeck.
Right ramus of lower jaw, magnified two diameters

a. Incisor. *b, c.* Line of vertical fracture behind the pre-molars. *d.* Three pre-molars, the third and last (much larger than the other two taken together) being divided by a crack. *e.* Sockets of two missing molars.

Up to 1857 all the mammalian remains discovered in secondary rocks had consisted solely of single branches of the lower jaw, but in that year Mr. Beckles obtained the upper portion of a skull and on the same slab the lower jaw of another quadruped with eight molars, a large canine, and a broad and thick incisor. It has been named Triconodon from its three-cone teeth, and is supposed to have been a small insectivorous marsupial, about the size of a hedgehog. Other jaws have since been found indicating a larger species of the same genus.

To the largest of these Professor Owen has given the name of *Triconodon major*. It was a carnivorous mammal, rather larger than the pole-cat (*Mustela putorius*), and equalling probably in size the *Dasyurus maugei* of Australia.[1]

Between forty and fifty pieces or sides of lower jaws with teeth have been found in oolitic strata in Purbeck; only five upper maxillaries, together with one portion of a separate cranium, occur at Stonesfield, and it is remarkable that with these there were no examples in Purbeck of an entire skeleton, nor of any considerable number of bones in juxtaposition. In several portions of the matrix there were detached bones, often much decomposed, and fragments of others apparently mammalian; but if all of them were restored, they would scarcely suffice to complete the five skeletons to which the five upper maxillaries above alluded to belonged. As the average number of pieces in each mammalian skeleton is about 250, there must be many thousands of missing bones; and when we endeavour to account for their absence, we are almost tempted to indulge in speculations like those once suggested to me by Dr. Buckland, when he tried to solve the enigma in reference to Stonesfield:—'The corpses,' he said, 'of drowned animals, when they float in a river, distended by gases during putrefaction, have often their lower jaw hanging loose, and sometimes it has dropped off. The rest of the body may then be drifted elsewhere, and sometimes may be swallowed entire by a predaceous reptile or fish, such as an ichthyosaur or a shark.'

As all the above-mentioned Purbeck marsupials, belonging to ten genera and to twenty-five species insectivorous, predaceous, and herbivorous, have been obtained from an area less than 500 square yards in extent, and from a single stratum not more than a few inches thick, we may safely conclude that the whole lived together in the same region, and in all likelihood they constituted a mere fraction of the mammalia which inhabited the lands drained by one river and its tributaries. They afford the first positive proof as yet obtained of the co-existence of a varied fauna of the highest class of vertebrata with that ample development of reptile life which marks all the periods from the

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[1] Owen, Fossil Mammalia of the Purbeck, Paleon. Soc. 1871.

Trias to the Lower Cretaceous inclusive, and with a gymnospermous flora, or that state of the vegetable kingdom when cycads and conifers predominated over all kinds of plants, except the ferns, so far at least as our present imperfect knowledge of fossil botany entitles us to speak.

The annexed table will enable the reader to see at a glance how conspicuous a part, numerically considered, the mammalian species of the Middle Purbeck now play when compared with those of other formations more ancient than the Paris gypsum, and at the same time it will help him to appreciate the enormous hiatus in the history of fossil mammalia, which at present occurs between the Eocene and Purbeck periods, and between the latter and the Stonesfield Oolite, and between this again and the Trias.

Number and Distribution of all the known Species of Fossil Mammalia from Strata older than the Paris Gypsum, or than the Bembridge Series of the Isle of Wight.

TERTIARY.	Headon Series and beds between the Paris Gypsum and the Grès de Beauchamp	14	10 English. 4 French.
	Barton Clay and Sables de Beauchamp . . .	0	
	Bagshot Beds, Calcaire Grossier, and Upper Soissonnais of Cuisse-Lamotte .	20	16 French. 1 English. 3 U. States.[1]
	London Clay, including the Kyson Sand . . .	7 English.	
	Plastic Clay and Lignite .	9	7 French. 2 English.
	Sables de Bracheux . .	1 French.	
	Thanet Sands and Lower Landenian of Belgium .	0	
SECONDARY.	Maestricht Chalk . .		
	White Chalk . . .	0	
	Chalk Marl . . .	0	
	Chloritic Series (Upper Greensand) . . .	0	
	Gault	0	
	Neocomian (Lower Greensand)	0	
	Wealden	0	

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[1] I allude to several Zeuglodons found in Alabama, and referred by some zoologists to three species.

SECONDARY (*continued*).	Upper Purbeck Oolite	0	
	Middle Purbeck Oolite	25	Swanage
	Lower Purbeck Oolite	0	
	Portland Oolite . .	0	
	Kimmeridge Clay .	0	
	Coral Rag . . .	0	
	Oxford Clay . .	0	
	Great Oolite . .	4	Stonesfield.
	Inferior Oolite . .	0	
	Lias	0	
	Upper Trias . . .	4	Wurtemberg. Somersetsh. N. Carolina.
	Middle Trias . .	0	
	Lower Trias . .	0	
PRIMARY.	Permian . . .	0	
	Carboniferous . .	0	
	Devonian . . .	0	
	Silurian . . .	0	
	Cambrian . . .	0	
	Laurentian . .	0	

The Sables de Bracheux, enumerated in the Tertiary division of the table, supposed by Mr. Prestwich to be somewhat newer than the Thanet Sands, and by M. Hébert to be of about that age, have yielded at La Fère the *Arctocyon (Palæocyon) primævus*, the oldest known tertiary mammal.

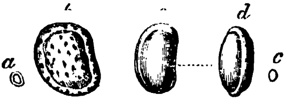
It is worthy of notice, that in the Hastings Sands there are certain layers of clay and sandstone in which numerous footprints of quadrupeds have been found by Mr. Beckles, and traced by him in the same set of rocks through Sussex and the Isle of Wight. They appear to belong to three or four species of reptiles, and no one of them to any warm-blooded quadruped. They ought, therefore, to serve as a warning to us, when we fail in like manner to detect mammalian footprints in older rocks (such as the New Red Sandstone), to refrain from inferring that quadrupeds, other than reptilian, did not exist or pre-exist.

But the most instructive lesson read to us by the Purbeck strata consists in this:—They are all, with the exception of a few intercalated brackish and marine layers, of freshwater origin; they are 160 feet in thickness, have been well searched by skilful collectors, and by the late Edward Forbes in particular, who studied them for months consecutively. They have been numbered, and the contents of each stratum recorded separately, by the officers of the Geological Survey of Great Britain.

They have been divided into three distinct groups by Forbes, each characterised by the same genera of pulmoniferous mollusca and cyprides, these genera being represented in each group by different species ; they have yielded insects of many orders, and the fruits of several plants ; and lastly, they contain 'dirt-beds,' or old terrestrial surfaces and vegetable soils at different levels, in some of which erect trunks and stumps of cycads and conifers, with their roots still attached to them, are preserved. Yet when the geologist enquires if any land animals of a higher grade than reptiles lived during any one of these three periods, the rocks are all silent, save one thin layer a few inches in thickness ; and this single page of the earth's history has suddenly revealed to us in a few weeks the memorials of so many species of fossil mammalia, that they already outnumber those of many a subdivision of the tertiary series, and far surpass those of all the other secondary rocks put together !

Lower Purbeck.—Beneath the thin marine band mentioned at p. 311 as the base of the Middle Purbeck some purely freshwater marls occur, containing species of *Cypris* (fig. 313 *a*, *c*), *Valvata*, and *Limnæa*, different from those of the Middle Purbeck. This is the beginning of the inferior division, which is about 80 feet thick. Below the marls are seen, at Meup's Bay, more than 30 feet of brackish-water strata, abounding in a species of *Serpula*, allied to, if not identical with, *Serpula coacervata*, found in beds of the same age in Hanover. There are also shells of the genus *Rissoa* (of the subgenus *Hydrobia*), and a little *Cardium* of the subgenus *Protocardium*, in these marine beds, together with *Cypris*. Some of the cypris-bearing shales are strangely contorted and broken up, at the west end of the Isle of Purbeck. The great dirt-bed or vegetable soil containing the roots and stools of *Cycadeæ*, which I shall presently describe, underlies these marls, and rests upon the lowest freshwater limestone, a rock about eight feet thick, containing *Cyclas*, *Valvata*, and *Limnæa*, of the same species as those of the uppermost part of the Lower Purbeck, or above the dirt-bed. The freshwater limestone in its turn rests upon the top beds of the Portland stone, which, although it contains purely marine remains, often consists of a rock undistinguishable in mineral character from the Lowest Purbeck limestone.

Fig. 313.

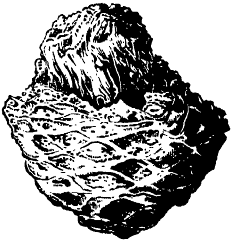


Cyprides from the Lower Purbeck.

a. *Cypris Purbeckensis*, Forbes.
b. Same magnified.
c. *Cypris punctata*, Forbes.
d, e. Two views magnified of the same.

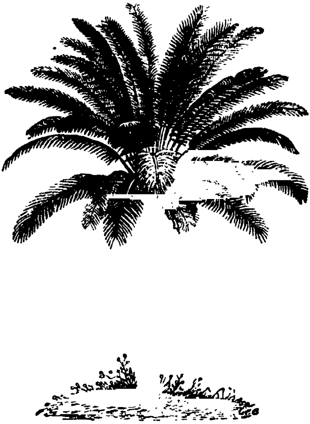
Dirt-bed or ancient surface soil.—The most remarkable of all the varied succession of beds enumerated in the above list, is that called by the quarrymen 'the dirt,' or 'black dirt,' which was evidently an ancient vegetable soil. It is from 12 to 18 inches thick, is of a dark brown or black colour, and contains a large proportion of earthy lignite. Through it are dispersed rounded and sub-angular fragments of stone, from 3 to 9 inches in diameter, in such numbers that it almost deserves the name of gravel. I also saw in 1866, in Portland, a smaller dirt-bed six feet below the principal one, six inches thick, consisting of brown earth with upright *Cycads* of the same species (*Mantellia nidiformis*, fig. 314) as those found in the upper bed, but no *Coniferæ*. The weight of the incumbent strata squeezing down the compressible dirt-bed has caused the *Cycads* to assume that form which has led the quarrymen to call them 'petrified birds' nests,' which suggested to Brongniart the specific name of *nidiformis*. I am indebted to Mr. Carruthers for the annexed figure of one of these Purbeck specimens, in which the original cylindrical figure has been less distorted than usual by pressure; and I add a figure of the living Cycas that the student may have an idea of a form so predominant in Mesozoic vegetation.

Fig. 314.



Mantellia nidiformis, Brongn. The upper part shows the woody stem; the lower part the bases of the leaves.

Fig. 315.



Cycas circinalis. Living in the East Indies.[1]

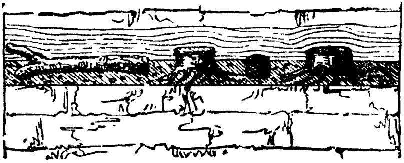
Many silicified trunks of coniferous trees, and the remains of plants allied to *Zamia* and *Cycas*, are buried in this dirt-bed, and must have become fossil on the spots where they grew.

[1] Hooker, Descriptive and Analytical Botany, 1873, p. 752.

The stumps of the trees stand erect for a height of from one to three feet, and even in one instance to six feet, with their roots attached to the soil at about the same distances from one another as the trees in a modern forest. The carbonaceous matter is most abundant immediately around the stumps, and round the remains of fossil *Cycadeæ.*

Besides the upright stumps above mentioned, the dirt-bed contains the stems of silicified trees laid prostrate. These are partly sunk into the black earth, and partly enveloped by a calcareous shale which covers the dirt-bed. The fragments of the prostrate trees are rarely more than three or four feet in length; but, by joining many of them together, trunks have been restored, having a length from the root to the branches of from 20 to 23 feet, the stems being undivided for 17 or 20 feet, and then forked. The diameter of these near the root is usually about one foot, but I measured one myself in 1866, which was 3½ feet in diameter, said by the quarrymen to be unusually large. Root-shaped cavities were observed by Professor Henslow to descend from the bottom of the dirt-bed into the subjacent freshwater stone, which, though now solid, must have been in a soft and penetrable state when the trees grew. The thin layers of calcareous shale (fig. 316) were evidently deposited tranquilly, and would have been horizontal but for the protrusion of the stumps of the trees, around the top of each of which they form hemispherical concretions.

Fig. 316.

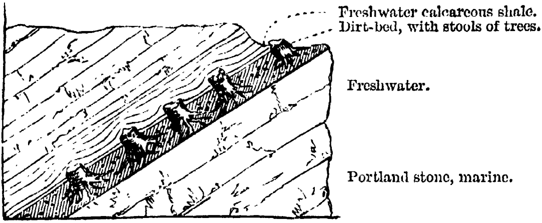

Freshwater calcareous shale.
Dirt-bed and ancient forest.
Lowest freshwater beds of the Lower Purbeck.
Portland stone, marine.

Section in Isle of Portland, Dorset. (Buckland and De la Beche.)

The dirt-bed is by no means confined to the island of Portland, where it has been most carefully studied, but is seen in the same relative position in the cliffs east of Lulworth Cove, in Dorsetshire, where, as the strata have been disturbed, and are now inclined at an angle of 45°, the stumps of the trees are also inclined at the same angle in an opposite direction—a beautiful illustration of a change in the position of beds originally horizontal (see fig. 317).

From the facts above described we may infer, first, that those beds of the Upper Oolite, called 'the Portland,' which are full of marine shells, were overspread with fluviatile mud, which became dry land, and covered by a forest, throughout a portion of the space now occupied by the South of England, the climate being such as to permit the growth of the *Zamia* and *Cycas*. 2ndly. This land at length sank down and was submerged with its forests beneath a body of fresh water, from which sediment was thrown down enveloping fluviatile shells. 3rdly. The regular and uniform preservation of this thin bed of black earth over a distance of many miles, shows that the change from dry land to the state of a freshwater lake or estuary, was not accompanied by any violent denudation, or rush of water, since the loose black earth, together with the trees which lay prostrate on its surface, must inevitably have been swept away had any such violent catastrophe taken place.

Fig. 317.



Section of cliff east of Lulworth Cove. (Buckland and De la Beche.)

The forest of the dirt-bed, as before hinted, was not everywhere the first vegetation which grew in this region. Besides the lower bed containing upright *Cycadeæ*, before mentioned, another has sometimes been found above it, which implies oscillations in the level of the same ground, and its alternate occupation by land and water more than once.

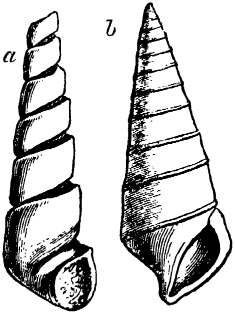
Sub-divisions of the Purbeck.—It will be observed that the division of the Purbecks into upper, middle, and lower, was made by Professor Forbes strictly on the principle of the entire distinctness of the species of organic remains which they include. The lines of demarcation are not lines of disturbance, nor indicated by any striking variations in physical or mineral character. The features which attract the eye in the Purbecks, such as the dirt-beds, the dislocated strata at Lulworth, and the Cinder-bed, do not indicate any breaks in the distribution of organised beings. 'The causes which led to a complete change of life three times during the deposition of the freshwater and brackish strata must,' says this naturalist, 'be sought for, not simply in either a rapid or a sudden change of their area into land or sea, but in the great lapse of time which intervened between the epochs of deposition at certain periods during their formation.'

Each dirt-bed may, no doubt, be the memorial of many thousand years or centuries, because we find that two or three feet of vegetable soil is the only monument which many a tropical forest has left of its existence ever since the ground on which it now stands was first covered with its shade. Yet, even if we imagine the fossil soils of the Lower Purbeck to represent as many ages, we need not be surprised to find that they do not constitute lines of separation between strata characterised by different zoological types. The preservation of a layer of vegetable soil, when in the act of being submerged, must be regarded as a rare exception to a general rule. It is of so perishable a nature, that it must usually be carried away by the denuding waves or currents of the sea, or by a river ; and many Purbeck dirt-beds were probably formed in succession and annihilated, besides those few which now remain.

The plants of the Purbeck beds, so far as our knowledge extends at present, consist chiefly of Ferns, Coniferæ, and Cycadæ (fig. 315), without any angiosperms ; the whole more allied to the Oolitic than to the Cretaceous vegetation. The same affinity is indicated by the vertebrate and invertebrate animals. Mr. Brodie has found the remains of beetles and several insects of the homopterous and neuropterous orders, some of which now live on plants, while others are of such forms as hover over the surface of our present rivers.

Portland Oolite and sand (*b*, Tab., p. 308).—The Portland oolite has already been mentioned as forming in Dorsetshire the foundation on which the freshwater limestone of the Lower Purbeck reposes (see p. 317). It supplies the well-known building-stone of which St. Paul's and so many of the principal edifices of London are constructed. About fifty species of mollusca occur in this formation, among which are some ammonites of large size. The cast of a spiral univalve called by the quarrymen the 'Portland screw' (*a*, fig. 318), is common ; the shell of the same (*b*) being rarely met with. Also *Trigonia gibbosa* (fig. 320) and *Cardium dissimile* (fig. 321). This

Fig. 318.

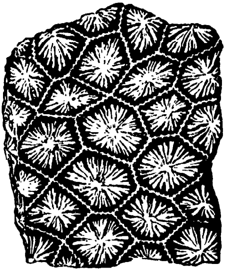


Cerithium Portlandicum (=*Terebra*), Sow.

a. Cast of shell known as 'Po land screw.'
b. The shell itself.

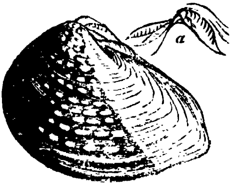
upper member rests on a dense bed of sand, called the Portland sand, containing similar marine fossils, below which is the Kimmeridge clay. In England these Upper Oolite formations are almost wholly confined to the southern counties. But some fragments of them occur beneath the Neocomian or Speeton clay on the coast of Yorkshire, containing many more fossils common to the Portlandian of the Continent than does the same

Fig. 319.



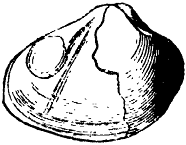
ea oblonga, M. Edw. and J. Haime.
Converted into chert from the Portland
Sand, Tisbury.

Fig. 320.



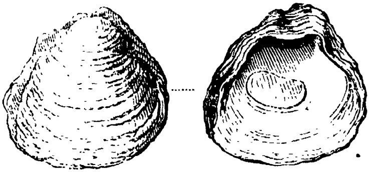
Trigonia gibbosa. ½ nat. size
a. The hinge.
Portland Stone, Tisbury.

Fig. 321.



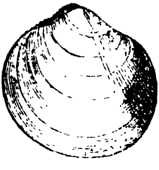
Cardium dissimile. ¼ nat. size.
Portland Stone.

Fig. 322.



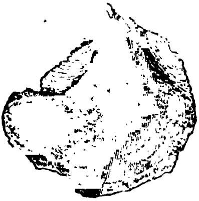
Ostrea expansa. Portland Sand.

Fig. 323.



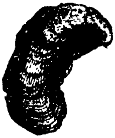
Cardium striatulum.
Kimmeridge Clay,
Hartwell.

Fig. 324.



Ostrea deltoidea,
Kimmeridge Clay, ¼ nat. size.

Fig. 325.



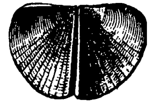
Gryphæa (*Exogyra*)
virgula.
Kimmeridge Clay

formation in Dorsetshire. Corals are rare in this formation, although one species is found plentifully at Tisbury, Wiltshire, in the Portland sand, converted into flint and chert, the original calcareous matter being replaced by silex (fig. 319).

Kimmeridge clay.—The *Kimmeridge clay* consists, in great part, of a bituminous shale, sometimes forming an impure coal, several hundred feet in thickness. In some places in Wiltshire it much resembles peat; and the bituminous matter may have been, in part at least, derived from the decomposition of vegetables. But as impressions of plants are rare in these shales, which contain ammonites, oysters, and other marine shells, with skeletons of fish and saurians, the bitumen may perhaps be of animal origin. Some of the saurians (Pliosaurus) in Dorsetshire are among the most gigantic of their kind.

Among the fossils, amounting to nearly 100 species, may be mentioned *Cardium striatulum* (fig. 323) and *Ostrea deltoidea* (fig. 324), the latter found in the Kimmeridge clay throughout England and the north of France, and also in Scotland, near Brora. The *Gryphæa virgula* (fig. 325), also met with in the Kimmeridge clay near Oxford, is so abundant in the Upper Oolite of parts of France, as to have caused the deposit to be termed 'marnes à gryphées virgules.' Near Clermont, in Argonne, a few leagues from St. Menehould, where these indurated marls crop out from beneath the gault, I have seen them, on decomposing, leave the surface of every ploughed field literally strewed over with this fossil oyster. The *Trigonellites latus* (*Aptychus*, of some authors) (fig. 326) is also widely dispersed through this clay. The real nature of the shell-like body, of which there are many species in oolitic rocks, is still a matter of conjecture. Some are of opinion that the two plates have been the gizzard of a cephalopod; others that it may have formed a bivalve operculum of the same.

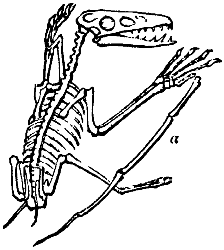
Fig. 326.



Trigonellites latus, Park.
Kimmeridge Clay.

Solenhofen stone.—The celebrated lithographic stone of Solenhofen in Bavaria, appears to be of intermediate age between the Kimmeridge clay and the Coral Rag, presently to be described. It affords a remarkable example of the variety of fossils which may be preserved under favourable circumstances, and what delicate impressions of the tender parts of certain animals and plants may be retained where the sediment is of extreme fineness. Although the number of testacea in this slate is small, and the plants few, and those all marine, Count Münster had determined no less than 237 species of fossils when I saw his collection in 1833; and among them no less than seven *species* of flying reptiles or pterodactyls (see fig. 327), six saurians, three tortoises, sixty species of fish, forty-six of crustacea, and twenty-six of insects. These insects, among which is a libellula, or dragon-fly, must have been blown out to sea, probably from the same land to which the Pterodactyls, and other contemporaneous air breathers, resorted.

Fig. 327.



Skeleton of *Pterodactylus* [illegible]

Oolite of Pappenheim, near Solenhofen.

The bone *a*, consisting of four joints, is part of the fifth or outermost digit elongated, for the support of a wing.

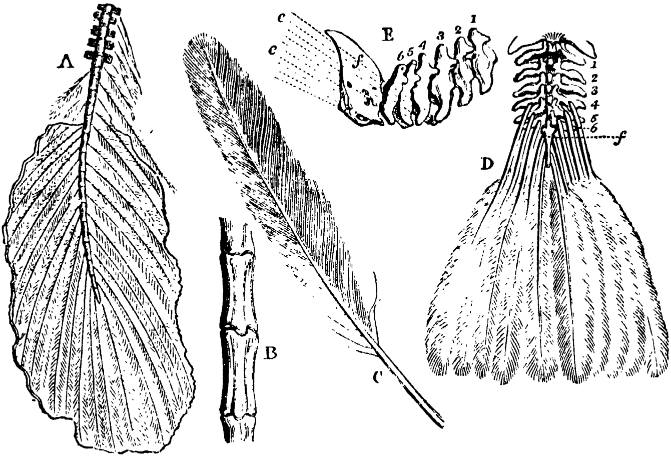
In the same slate of Solenhofen a fine example was met with in 1862 of the skeleton of a bird almost entire, and retaining even its feathers so perfect that the vanes as well as the shaft are preserved. The head was at first supposed to be wanting, but Mr. Evans detected on the slab what seems to be the impression of the cranium and beak, much resembling in size and shape that of the jay or woodcock. This valuable specimen is now in the British Museum, and has been called by Professor Owen *Archæopteryx macrura*. Although anatomists agree that it is a true bird, yet they also find that in the length of the bones of the tail, and some other minor points of its anatomy, it approaches more nearly to reptiles than any known living bird. In the living representatives of the class Aves, the tail feathers are attached to a coccygian bone, consisting of several vertebræ united together; whereas in the Archæopteryx the tail is composed of twenty vertebræ, each of which supports a pair of quill feathers. The first five only of the vertebræ, as seen in A (fig. 328), have transverse processes, the fifteen remaining ones become gradually longer and more tapering. The feathers diverge outward from them at an angle of 45°.

Professor Huxley in his late memoir on the order of reptiles called Dinosaurians, which are largely represented in all the formations, from the Neocomian to the Trias inclusive, has shown that they present in their structure many remarkable affinities to birds. But a reptile about two feet long, called Compsognathus, lately found in the Stonesfield slate, makes a much greater approximation to the class Aves than any Dinosaur, and therefore forms a closer link between the classes Aves and Reptilia than does the Archæopteryx.

It appears doubtful whether any species of British fossil whether of the vertebrate or invertebrate class, is common to the

Oolite and Chalk. But there is no similar break or discordance as we proceed downwards, and pass from one to another of the

Fig. 328.



Tail and feather of *Archæopteryx*, from Solenhofen, and tail of living bird for comparison.

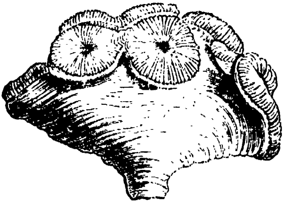
A. Caudal vertebræ of *Archæopteryx macrura*, Owen; with impression of tail feathers. ⅕ nat. size.
B. Two caudal vertebræ of same, nat. size
C. Single feather, found in 1861 at Solenhofen, by Von Meyer, and called *Archæopteryx lithographica*. Nat. size.
D. Tail of recent vulture (*Gyps Bengalensis*), showing attachment of tail-feathers in living birds. ¼ nat. size.
E. Profile of caudal vertebræ of same. ¼ nat. size. *c*, *c*. Direction of tail-feathers when seen in profile. *f*. Ploughshare bone or broad terminal joint (seen also in *f*, D.)

several leading members of the Jurassic group, the Upper, Middle, and Lower Oolite, and the Lias, there being often a considerable proportion of the mollusca, sometimes as much as a fourth, common to such divisions as the Upper and Middle Oolite.

MIDDLE OOLITE.

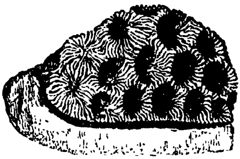
Coral Rag.—One of the limestones of the Middle Oolite has been called the 'Coral Rag,' because it consists, in part, of continuous beds of petrified corals, most of them retaining the position in which they grew at the bottom of the sea. In their forms they more frequently resemble the reef-building polyparia of the Pacific than do the corals of any other member of the Oolite. They belong chiefly to the genera *Thecosmilia* (fig. 329), *Protoseris*, and *Thamnastræa*, and sometimes form masses of coral fifteen feet thick. In the annexed figure of a *Thamnastræa* (fig. 330), from this formation, it will be seen that the cup-shaped cavities are deepest on the right-hand side, and that they grow more and more shallow, until those on the left side are nearly filled up. The last-mentioned stars are supposed to represent a perfected condition, and the others an immature state. These coralline strata extend through the calcareous hills of the north-west of Berkshire, and north of Wilts, and again recur in Yorkshire, near Scarborough. The *Ostrea gregarea* (fig. 331) is very characteristic of the formation in England and on the Continent.

Fig. 329.



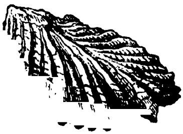
Thecosmilia annularis, Milne Edw. and J. Haime. Coral Rag, Steeple Ashton.

Fig. 330.



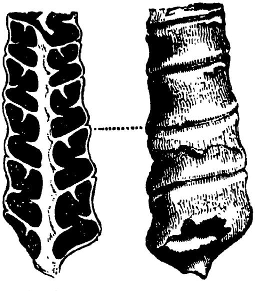
Thamnastræa. Coral Rag, Steeple Ashton.

Fig. 331.



Ostrea gregarea. Coral Rag, Steeple Ashton.

Fig. 332.

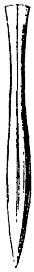


Nerinæa Goodhallii, Fitton. Coral Rag, Weymouth. ¼ nat. size.

One of the limestones of the Jura, referred to the age of the English coral rag, has been called 'Nerinæan limestone' (Calcaire à Nérinées) by M. Thirria; *Nerinæa* being an extinct genus of univalve shells (fig. 332) much resembling *Cerithium* in external form. The annexed section shows the curious and continuous ridges on the columella and whorls.

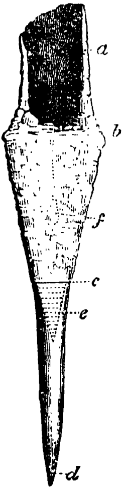
Oxford clay.—The coralline limestone, or 'coral rag,' above described, and the accompanying sandy beds, called 'calcareous grits,' of the Middle Oolite, rest on a thick bed of clay, called the 'Oxford Clay,' sometimes not less than 600 feet thick. In this there are no corals, but great abundance of cephalopoda, of the genera Ammonite and Belemnite (see figs. 333 and 334). In some of the finely laminated clays ammonites are very perfect, although somewhat compressed, and are frequently found with the lateral lobe extended on each side of the aperture into a horn-like projection (see fig. 334). These were discovered in the cuttings of the Great Western Railway, near Chippenham, in 1841, and have been described by Mr. Pratt (*An. Nat. Hist.*, Nov. 1841).

Fig. 333.



Belemnites hastatus.
Oxford Clay.

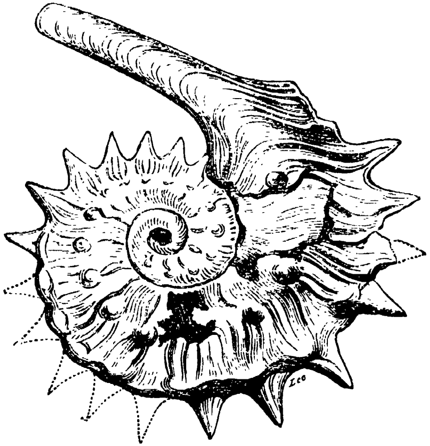
Fig. 335.



Belemnites Puzosianus, d'Orb.
B. Owenii, Pierce.
Oxford Clay, Christian Malford.

a. Section of the shell projecting from the phragmacone.
b–c. External covering to the ink-bag and phragmacone.
c, d. Osselet, or that portion commonly called the belemnite.
e. Conical chambered body called the phragmacone.
f. Position of ink-bag beneath the shelly covering.

Fig. 334.



Ammonites Jason, Reinecke. (Syn. *A. Elizabethæ*, Pratt.)
Oxford Clay, Christian Malford, Wiltshire.

Similar elongated processes have been also observed to extend from the phragmacone of some belemnites discovered by Dr. Mantell in the same clay (see fig. 335), who, by the aid of this and other specimens, has been able to throw much light on the structure of singular extinct forms of cuttle fish.[1]

Kelloway rock.—The arenaceous limestone which passes under this name is generally grouped as a member of the Oxford clay, in which it forms, in the south-west of England, lenticular masses, 8 or 10 feet thick, containing at Kelloway, in Wiltshire, numerous casts of ammonites, and other shells. But in Yorkshire this calcareo-arenaceous formation thickens to about 30 feet, and constitutes the lower part of the Middle Oolite, extending inland from Scarborough in a southerly direction. The number of mollusca which it contains is, according to Mr. Etheridge, 143, of which only 34, or 23⅔ per cent., are common to the Oxford clay proper. Of the 52 Cephalopoda, fifteen (namely 13 species of ammonite, the *Ancyloceras Calloviense* and one Belemnite) are common to the Oxford clay, giving a proportion of nearly 30 per cent.

LOWER OOLITE.

Cornbrash and Forest Marble.—The upper division of this series, which is more extensive than the preceding or Middle Oolite, is called in England the Cornbrash, as being a brashy, easily broken rock, good for corn land. It consists of clays and calcareous sandstones, which pass downwards into the Forest Marble, an argillaceous limestone, abounding in marine fossils. In some places, as at Bradford, this limestone is replaced by a mass of clay. The sandstones of the Forest Marble of Wiltshire are often ripple-marked and filled with fragments of broken shells and pieces of drift-wood, having evidently been formed on a coast. Rippled slabs of fissile oolite are used for roofing, and have been traced over a broad band of country from Bradford in Wilts, to Tetbury in Gloucestershire. These calcareous tile-stones are separated from each other by thin seams of clay, which have been deposited upon them, and have taken their form, preserving the undulating ridges and furrows of the sand in such complete integrity, that the impressions of small footsteps, apparently of crustaceans, which walked over the soft, wet sands, are still visible. In the same stone the claws of crabs, fragments of echini, and other signs of a neighbouring beach, are still observed.[2]

Great (or Bath) Oolite.—Although the name of coral rag has been appropriated, as we have seen, to the highest member of the Middle Oolite before described, some portions of the

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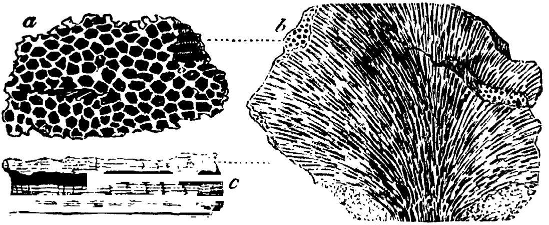
[1] See Phil. Trans. 1850, p. 363; also Huxley, Memoirs of Geol. Survey, 1864; Phillips, Paleont. Soc.

[2] P. Scrope, Proc. Geol. Soc., March 1831.

Lower Oolite are equally entitled in many places to be called coralline limestones. Thus the Great Oolite near Bath contains various corals, among which the *Eunomia radiata* (fig. 336) is very conspicuous, single individuals forming masses several feet in diameter; and having probably required, like the large existing brain-coral (*Meandrina*) of the tropics, many centuries before their growth was completed.

Fig. 336.

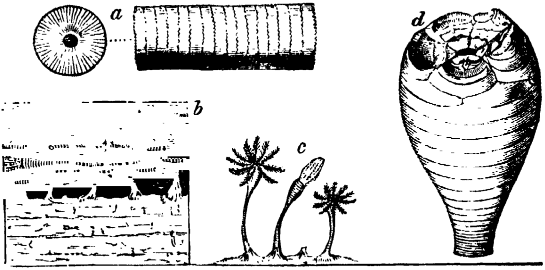


Eunomia radiata, Lamouroux. (*Calamophyllia*, Milne Edw.)

a. Section transverse to the tubes.
b. Vertical section, showing the radiation of the tubes.
c. Portion of interior of tubes magnified, showing striated surface.

Different species of crinoids, or stone-lilies, are also common in the same rocks with corals; and, like them, must have lived on a firm bottom, where their base of attachment remained undisturbed for years (*c*, fig. 337). Such fossils, therefore, are almost confined to the limestones; but an exception occurs at Bradford, near Bath, where they are enveloped in clay some-

Fig. 337.

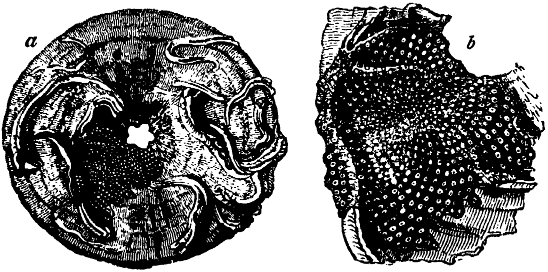


Apiocrinites rotundus, or Pear Encrinite; Miller. Fossil at Bradford, Wilts.

a. Stem of *Apiocrinites*, and one of the articulations, natural size.
b. Section at Bradford of Great Oolite and overlying clay, containing the fossil encrinites.
c. Three perfect individuals of *Apiocrinites*, represented as they grew on the surface of the Great Oolite.
d. Body of the *Apiocrinites rotundus*. Half nat. size.

times 60 feet thick. In this case, however, it appears that the solid upper surface of the 'Great Oolite' had supported, for a time, a thick submarine forest of these beautiful crinoids, until the clear and still water was invaded by a current charged with mud, which threw down the stone-lilies, and broke most of their stems short off near the point of attachment. The stumps still remain in their original position; but the numerous articulations, once composing the stem, arms, and body of the encrinite, were scattered at random through the argillaceous deposit in which some now lie prostrate. These appearances are represented in the section *b*, fig. 337, where the darker strata represent the Bradford clay, which is, however, a formation of such local development that in many places it cannot be easily separated from the clays of the overlying 'forest-marble' and underlying 'fuller's earth.' The upper surface of the calcareous stone below is completely incrusted over with a continuous pavement, formed by the stony roots or attachments of the Crinoidea; and, besides this evidence of the length of time they had lived on the spot, we find great numbers of single joints, or circular plates of the stem and body of the encrinite, covered over with *serpulæ*. Now these *serpulæ* could only have begun to grow after the death of some of the stone-lilies, parts of whose skeletons had been strewed over the floor of the ocean before the irruption of argillaceous mud. In some instances we find that, after the parasitic *serpulæ* were full grown, they had become incrusted over with a polyzoan, called *Diastopora diluviana* (see *b*, fig. 338); and many generations of these molluscoids had succeeded each other in the pure water before they became fossil.

Fig. 338.



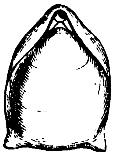
a. Single plate of body of *Apiocrinus*, overgrown with *serpulæ* and *polyzoa*. Natural size. Bradford Clay.
b. Portion of the same magnified, showing the polyzoan *Diastopora diluviana* covering one of the *serpulæ*.

Such differences in the fossils as distinguish the calcareous and argillaceous deposits from each other, would be described by naturalists as arising out of a difference in the *stations* of species; but besides these, there are variations in the fossils of the higher, middle, and lower part of the oolitic series, which must be ascribed to that great law of change in organic life by which distinct assemblages of species have been adapted, at successive geological periods, to the varying conditions of the habitable surface. In a single district it is difficult to decide how far the limitation of species to certain minor formations has been due to the local influence of *stations*, or how far it has been caused by time or the law of variation above alluded to. But we recognise the reality of the last-mentioned influence, when we contrast the whole oolitic series of England with that of parts of the Jura, Alps, and other distant regions, where, although there is scarcely any lithological resemblance, yet some of the same fossils remain peculiar in each country to the Upper, Middle, and Lower Oolite formations respectively. Mr. Thurmann has shown how remarkably this fact holds true in the Bernese Jura, although the argillaceous divisions, so conspicuous in England, are feebly represented there, and some entirely wanting.

The calcareous portion of the Great Oolite consists of several shelly limestones, one of which, called the Bath Oolite, is much celebrated as a building-stone. In parts of Gloucestershire, especially near Minchinhampton, the Great Oolite, says Mr. Lycett, 'must have been deposited in a shallow sea, where strong currents prevailed, for there are frequent changes in the mineral character of the deposit, and some beds exhibit false stratification. In others, heaps of broken shells are mingled with pebbles of rocks foreign to the neighbourhood, and with fragments of abraded madrepores, dicotyledonous wood, and crabs' claws. The shelly strata, also, have occasionally suffered denudation, and the removed portions have been replaced by clay.' In such shallow-water beds shells of the genera *Patella*, *Nerita*, *Rimula*, and *Cylindrites* are common (see figs. 341 to 344); while cephalopods are rare, and, instead of ammonites and belemnites, numerous genera of carnivorous trachelipods appear.

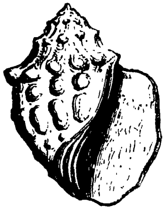
Out of 224 species of univalves obtained from the Minchinhampton beds, Mr. Lycett found no less than 50 to be carnivorous. They belong principally to the genera *Buccinum*, *Pleurotoma*, *Rostellaria*, *Murex*, *Purpuroidea* (fig. 340), and *Fusus*, and exhibit a proportion of zoophagous species not very different from that which obtains in seas of the Recent period. These zoological results are curious and unexpected, since it was imagined that we might look in vain for the carnivorous trachelipods in rocks of such high antiquity as the Great Oolite, and it was a received doctrine that they did not begin to appear in considerable numbers till the Eocene period, when those two great families of cephalopoda, the Ammonites and Belemnites, and a great number of other representatives of the same class of chambered shells, had become extinct.

Fig. 339.



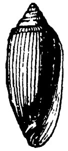
Terebratula digona, Sow.
Nat. size. Bradford Clay.

Fig. 340.



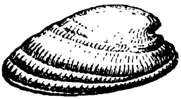
Purpuroidea nodulata.
¼ nat. size. Great
Oolite, Minchinhampton.

Fig. 341.



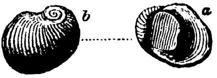
Cylindrites acutus, Sow.
Syn. *Actæon acutus.*
Great Oolite,
Minchinhampton.

Fig. 342.



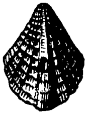
Patella rugosa, Sow.
Great Oolite.

Fig. 343.



Nerita costulata, Desh.
Great Oolite.

Fig. 344.



Rimula (Emarginula) clathrata, Sow.
Great Oolite.

Stonesfield slate: Mammalia.—The slate of Stonesfield has been shown by Mr. Londsdale to lie at the base of the Great Oolite.[1] It is a slightly oolitic shelly limestone, forming large lenticular masses embedded in sand, only 6 feet thick, but very rich in organic remains. It contains some pebbles of a rock very similar to itself, and which may be portions of the deposit, broken up on a shore at low water or during storms, and redeposited. The remains of belemnites, trigoniæ, and other

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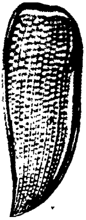
[1] Proceedings Geol. Soc., vol. i. p. 414.



Elytron of Buprestis? Stonesfield.

But the remarkable fossils for which the Stonesfield slate is most celebrated are those referred to the mammiferous class. The student should be reminded that in all the rocks described in the preceding chapters as older than the Eocene, no bones of any land-quadruped, or of any cetacean, had been discovered until the *Spalacotherium* of the Purbeck beds came to light in 1854. Yet we have seen that terrestrial plants were not wanting in the Upper Cretaceous formation (see p. 285), and that in the Wealden there was evidence of freshwater sediment on a large scale, containing various plants, and even ancient vegetable soils. We had also in the same Wealden many land-reptiles and winged insects, which render the absence of terrestrial quadrupeds the more striking. The want, however, of any bones of whales, seals, dolphins, and other aquatic mammalia, whether in the chalk or in the Upper or Middle Oolite, is certainly still more remarkable.

These observations are made to prepare the reader to appreciate more justly the interest felt by every geologist in the discovery in the Stonesfield slate (see table, p. 315) of no less than ten specimens of lower jaws of mammiferous quadrupeds, belonging to four different species and to three distinct genera, for which the names of *Amphitherium*, *Phascolotherium*, and *Stereognathus* have been adopted.

It is now generally admitted that these are really the remains of mammalia (although it was at first suggested that they might be reptiles), and the only question open to controversy is limited to this point, whether the fossil mammalia found in the Lower Oolite of Oxfordshire ought to be referred to the marsupial quadrupeds, or to the ordinary placental series. Cuvier had long ago pointed out a peculiarity in the form of the angular

Fig. 316.

Tupaia Tana.
Right ramus of lower jaw.
Natural size.
A recent insectivorous placental mammal, from Sumatra

process (*c*, figs. 349 and 350) of the lower jaw, as a character of the genus *Didelphys;* and Professor Owen has since confirmed the doctrine of its generality in the entire marsupial series. In all these pouched quadrupeds this process is turned inwards, as at *c, d,* fig. 349, in the Brazilian opossum, whereas in the placental series, as at *c,* figs. 347 and 348, there is an almost entire absence of such inflection. The *Tupaia Tana* of Sumatra has been selected by Mr. Waterhouse for this illustration, because the jaws of that small insectivorous quadruped bear a great resemblance to those of the Stonesfield *Amphitherium.* By clearing away the matrix from the specimen of *Amphitherium* *Prevostii* here represented (fig. 351), Professor Owen ascertained that the angular process (*c*) bent inwards in a slighter degree than in any of the known marsupialia; in short, the inflection does not exceed that of the mole or hedgehog. This fact made him doubt whether the *Amphitherium* might not be an insectivorous placental, although it offered some points of ap-

Fig. 347.

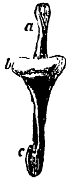
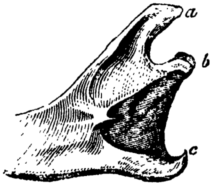


Fig. 348.



Part of lower jaw of *Tupaia Tana.*
Twice natural size.

Fig. 347. End view seen from behind, showing the very slight inflection of the angle at *c.*
Fig. 348. Side view of same.

Fig. 349.

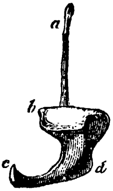
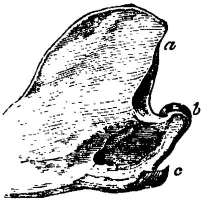


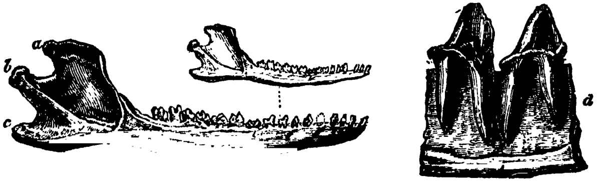
Fig. 350.



Part of lower jaw of *Didelphys Azaræ;*
recent, Brazil. Natural size.

Fig. 349. End view seen from behind, showing the inflection of the angle of the jaw, *c, d.*
Fig. 350. Side view of same.

Fig. 351.
Natural size.

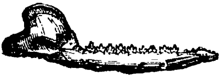


Amphitherium Prevostii, Cuv. sp. Stonesfield Slate.
Syn. *Thylacotherium Prevostii,* Valenc.

a. Coronoid process. *b.* Condyle. *c.* Angle of jaw. *d.* Double-fanged molars.

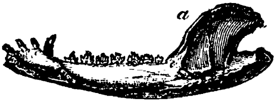
proximation in its osteology to the marsupials, especially to the *Myrmecobius*, a small insectivorous quadruped of Australia which has nine molars on each side of the lower jaw, besides a canine and three incisors.[1] Another species of *Amphitherium* has been found at Stonesfield (fig. 352), which differs from the former (fig. 351) principally in being larger.

Fig. 352.



Amphitherium Broderipii, Owen. Natural size. Stonesfield Slate.

Fig. 353.

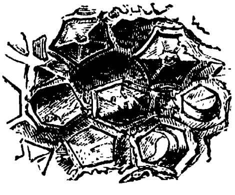


Phascolotherium Bucklandi, Broderip, sp.
a. Natural size.
b. Molar of same, magnified.

The second mammiferous genus discovered in the same slates was named originally by Mr. Broderip *Didelphys Bucklandi* (see fig. 353), and has since been called *Phascolotherium* by Owen. It manifests a much stronger likeness to the marsupials in the general form of the jaw, and in the extent and position of its inflected angle, while the agreement with the living genus *Didelphys* in the number of the pre-molar and molar teeth is complete.[2]

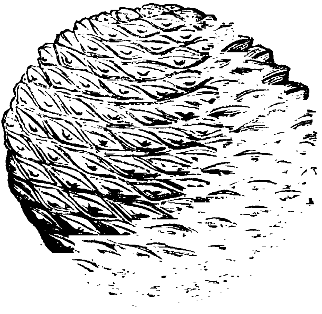
In 1854 the remains of another mammifer, small in size, but larger than any of those previously known, was brought to light. The generic name of *Stereognathus* was given to it, and, as is usually the case in these old rocks (see above, p. 314), it

Fig. 354.



Portion of a fossil fruit of *Podocarya Bucklandi*, Ung., magnified. (Buckland's Bridgw. Treatise, Pl. 63.) Inferior Oolite, Charmouth, Dorset.

Fig. 355.



Cone of fossil *Araucaria Sphærocarpa*, Carr. Inferior Oolite. Bruton, Somersetshire. ⅓ diameter of original. In the collection of the British Museum.

[1] A figure of this recent *Myrmecobius* will be found in my Principles of Geology, chap. ix.

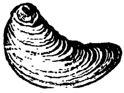
[2] Owen's British Fossil Mammals, p. 62.

consisted of part of a lower jaw, in which were implanted three double-fanged teeth, differing in structure from those of all other known recent or extinct mammals.

Plants of the Oolite.—The Araucarian pines, which are now abundant in Australia and its islands, together with marsupial quadrupeds, are found in like manner to have accompanied the marsupials in Europe during the Oolitic period (see fig. 355). In the same rock endogens of the most perfect structure are met with, as, for example, fruits allied to the Pandanus, such as the *Kaidacarpum ooliticum* of Carruthers in the Great Oolite and the *Podocarya* of Buckland (see fig. 354) in the Inferior Oolite.

Fuller's Earth.—Between the Great and Inferior Oolite in the West of England, an argillaceous deposit, called 'the fuller's earth,' occurs; but it is wanting in the north of England. It abounds in the small oyster represented in fig. 356. The number of mollusca known in this deposit is about seventy; namely, fifty Lamellibranchiate Bivalves, ten Brachiopods, three Gasteropods, and seven or eight Cephalopods.

Fig. 356.



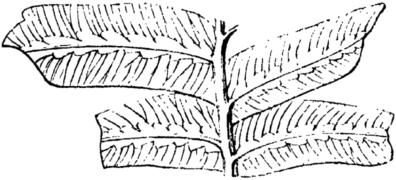
Ostrea acuminata.
Fuller's Earth.

Inferior Oolite.—This formation consists of a calcareous freestone, usually of small thickness, but attaining in some places, as in the typical area of Cheltenham and the Western Cotswolds, a thickness of 250 feet. It sometimes rests upon yellow sands, formerly classed as the sands of the Inferior Oolite, but now regarded as a member of the Upper Lias. These sands repose upon the Upper Lias clays in the south and west of England. The Collyweston slate, formerly classed with the Great Oolite, and supposed to represent in Northamptonshire the Stonesfield slate, is now found to belong to the Inferior Oolite, both by community of species and position in the series. The Collyweston beds, on the whole, assume a much more marine character than the Stonesfield slate. Nevertheless, one of the fossil plants (*Aroides Stutterdi*, Carr.), remarkable, like the Pandanaceous species before-mentioned (fig. 354), as a representative of the monocotyledonous class, is common to the Stonesfield beds in Oxfordshire.

The Inferior Oolite of Yorkshire consists largely of shales and sandstones, which assume much the aspect of a true coal-field, thin seams of coal having actually been worked in them for more than a century. A rich harvest of fossil ferns has been obtained from them, as at Gristhorpe, near Scarborough (fig. 357). They contain also Cycadæ, of which family a magnificent specimen has been described by Mr. Williamson under the name Zamia Gigas, and a fossil called *Equisetum Columnare* (see fig.

404, p. 364), which maintains an upright position in sandstone strata over a wide area. Shells of *Estheria* and *Unio*, collected by Mr. Bean from these Yorkshire coal-bearing beds, point to the estuary or fluviatile origin of the deposit.

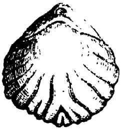
Fig. 357.



Hemitelites Brownii, Goepp. Syn. *Phlebopteris contigua*, Lind. and Hutt.
Lower carbonaceous strata, Inferior Oolite shales. Gristhorpe, Yorkshire.

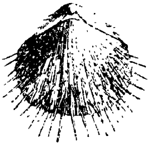
At Brora, in Sutherlandshire, a coal seam probably coeval with the above,[1] or at least belonging to the Kelloway Rock, the lowest marine bed of the Oolitic period, was extensively mined nearly a century ago. It affords the thickest stratum of pure vegetable matter hitherto detected in any secondary rock in England, upwards of 80,000 tons having been extracted. One

Fig. 358.



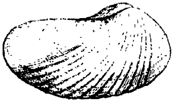
Terebratula fimbria, Sow.
Inferior Oolite marl,
Cotswold Hills.

Fig. 359.



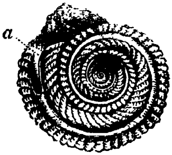
Rhynchonella spinosa,
Schloth.
Inferior Oolite.

Fig. 360.



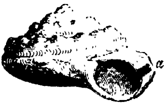
Pholadomya fidicula, Sow.
½ natural size.
Inferior Oolite.

Fig. 361.



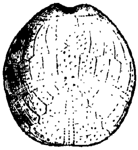
Pleurotomaria granulata, Sow.
Ferruginous Ool., Normandy.
Inferior Oolite, England.
Under side.

Fig. 362.



Pleurotomaria ornata,
Sow. Sp.
Inferior Oolite.
⅓ nat. size.

Fig. 363.



Collyrites (*Dysaster*) *ringens*, Agass.
Inf. Ool., Somersetshire.

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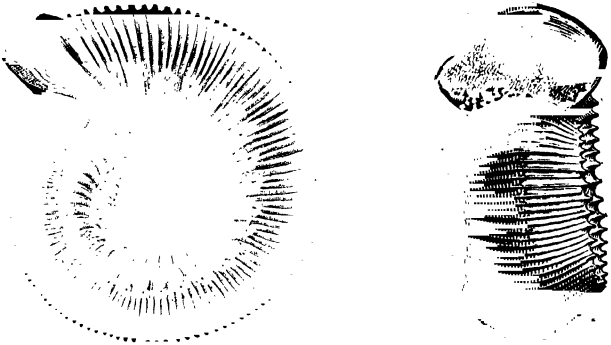
[1] See Judd, Quart. Geol. Journ., vol. xxix. p. 164.

seam of coal of good quality, 3½ feet thick, is now being worked, and there is pyritous coal resting upon it. The roof-bed of the coal is literally composed of marine shells, such as *Pholadomya*, *Trigonia*, *Goniomya*, *Pteroperna*, *Cerithium*, &c.

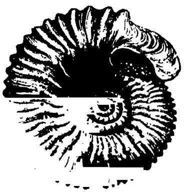
Among the characteristic shells of the Inferior Oolite, I may instance *Terebratula fimbria* (fig. 358), *Rhynchonella spinosa* (fig. 359), and *Pholadomya fidicula* (fig. 360). The extinct genus *Pleurotomaria* is also a form very common in this division as well as in the Oolitic system generally. It resembles *Trochus* in form, but is marked by a deep cleft (*a*, figs. 361, 362) on one side of the aperture. The *Collyrites* (*Dysaster*) *ringens* (fig. 363) is an Echinoderm common to the Inferior Oolite of England and France, as are the two Ammonites (figs. 364, 365).

Fig. 364.



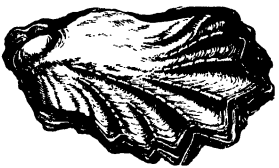
Ammonites Humphresianus, Sow. Inferior Oolite.

Fig. 365.



Ammonites Braikenridgii, Sow.
Oolite, Scarborough.
Inf. Ool., Dundry; Calvados; &c.

Fig. 366.



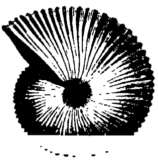
Ostrea Marshii. ½ natural size.
Middle and Lower Oolite.

Palæontological relations of the Oolitic strata.—Observations have already been made (p. 324) on the distinctness of the organic remains of the Oolitic and Cretaceous strata, and the proportion of species common to the different members of the Oolite. Between the Lower Oolite and the Lias there is a somewhat greater break, for out of 256 mollusca of the Upper Lias, thirty-seven species only pass up into the Inferior Oolite.

In illustration of shells having a great vertical range, it may be stated that in England some few species pass up from the Lower to the Upper Oolite, as, for example, *Rhynchonella obsoleta*, *Lithodomus inclusus*, *Pholadomya ovalis*, and *Trigonia costata*.

Of all the Jurassic Ammonites of Great Britain, *A. macrocephalus* (fig. 367), which is common to the Great Oolite and Oxford Clay, has the widest range.

Fig. 367.



Ammonites macrocephalus Schloth. ½ nat. size. Great Oolite and Oxford Clay.

We have every reason to conclude that the gaps which occur, both between the larger and smaller sections of the English Oolites, imply intervals of time elsewhere represented by fossiliferous strata, although no deposit may have taken place in the British area. This conclusion is warranted by the partial extent of many of the minor and some of the larger divisions even in England.

CHAPTER XX.

JURASSIC GROUP—*continued.* LIAS.

Mineral character of Lias—Numerous successive Zones in the Lias, marked by distinct fossils, without unconformity in the stratification, or change in the mineral character of the deposits—Gryphite limestone—Shells of the Lias—Fish of the Lias—Reptiles of the Lias—Ichthyosaur and Plesiosaur—Marine Reptile of the Galapagos Islands—Sudden destruction and burial of fossil animals in Lias—Fluvio-marine beds in Gloucestershire, and insect limestone—Fossil plants—Origin of the Oolite and Lias, and of alternating calcareous and argillaceous formations.

Lias.—The English provincial name of Lias has been very generally adopted for a formation of argillaceous limestone, marl, and clay, which forms the base of the Oolite, and is classed by many geologists as part of that group. The peculiar aspect which is most characteristic of the Lias in England, France, and Germany, is an alternation of thin beds of blue or grey limestone, having a surface which becomes light-brown when weathered, these beds being separated by dark-coloured, narrow argillaceous partings, so that the quarries of this rock, at a distance, assume a striped and riband-like appearance.

The Lias has been divided in England into three groups, the Upper, Middle, and Lower. The Upper Lias consists in places, first of sands, which were formerly regarded as the base of the Oolite, but which, according to Dr. Wright, are by their fossils more properly referable to the Lias; secondly, of clay shale and thin beds of limestone. The Middle Lias, or marlstone series, has been divided into three zones; and the Lower Lias, according to the labours of Quenstedt, Oppel, Strickland, Wright, and others, into seven zones, each marked by its own group of fossils. This Lower Lias averages from 600 to 900 feet in thickness.

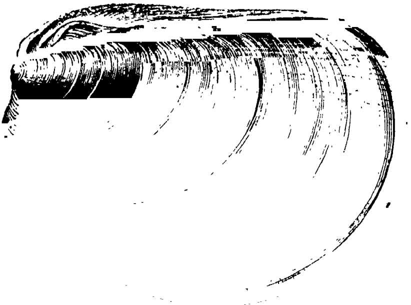
From Dorsetshire to Yorkshire all these divisions, observes Professor Ramsay, are constant; and from top to bottom we cannot assert that anywhere there is actual unconformity between any two subdivisions, whether of the larger or smaller kind.

In the whole of the English Lias, there are at present known about 1,000 species of mollusca, and of these 267 are Cephalopods, of which class more than two-thirds are Ammonites the Nautilus and Belemnite also abounding. The whole series has been divided by zones characterised by particular ammonites; for while other families of shells pass from one division to another in numbers varying from about 20 to 50 per cent., these cephalopods are almost always limited to single zones, as Quenstedt and Oppel have shown for Germany, and Dr. Wright and others for England.

As no actual unconformity is known from the top of the Upper to the bottom of the Lower Lias, and a general uniformity in the mineral character of almost all the strata is apparent, it is somewhat difficult to account even for such partial breaks as have been alluded to in the succession of species, if we reject the hypothesis that the old species were in each case destroyed at the close of the deposition of certain rocks containing them, and replaced by the creation of new forms when the succeeding formation began. I agree with Professor Ramsay in not accepting this hypothesis. No doubt some of the old species occasionally died out, and left no representatives in Europe or elsewhere; others were locally exterminated in the struggle for life by species which invaded their ancient domain, or by varieties better fitted for a new state of things. Pauses also of vast duration may have occurred in the deposition of strata, allowing time for the modification of organic life throughout extensive areas, slowly brought about by variation accompanied by extinction of some of the original forms.

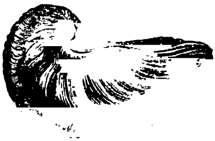
Fossils of the Lias.—The name of Gryphite limestone has sometimes been applied to the Lower Lias, in consequence of the great number of shells which it contains of a species of oyster, or *Gryphæa* (fig. 369). A large heavy shell called *Hippopodium*

Fig. 368.



Plagiostoma (*Lima*) *gigantea*, Sow.
Inferior Oolite and Lias.

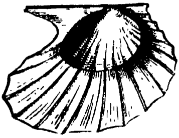
Fig. 369.



Gryphæa incurva, Sow.
(*G. arcuata*, Lam.) Lias.

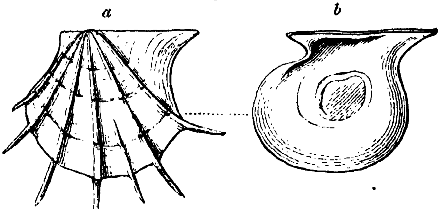
(fig. 372), allied to *Cypricardia*, is also characteristic of the upper part of the Lower Lias. In this formation occur also the Aviculas, figs. 370 and 371. The Upper Lias formation is also remarkable for being the newest of the secondary rocks in which the two genera of brachiopoda, *Spiriferina* and *Leptæna* (figs. 373, 374), occur, although the former is slightly modified in structure so as to constitute the subgenus Spiriferina (Davidson), and the Leptæna has dwindled in size to a shell smaller than a pea. No less than eight or nine species of Spiriferina are enumerated by Mr. Davidson as belonging to the Lias.

Fig. 370.



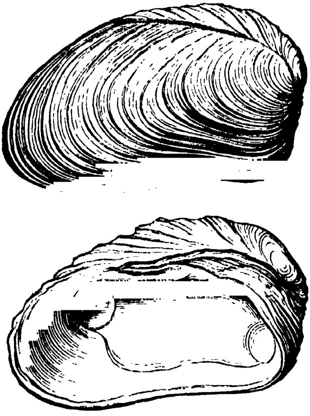
Avicula inæquivalvis, Sow.
Lower Lias.

Fig. 371.



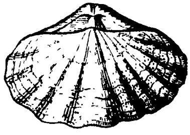
Avicula cygnipes, Phil. Lower Lias, Gloucestershire and Yorkshire.
a. Lower valve. *b.* Upper valve.

Fig. 372.



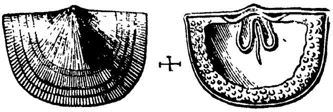
Hippopodium ponderosum, Sow.
½ diameter. Lias, Cheltenham.

Fig. 37



Spiriferina (*Spirifera*) *Walcotii*, Sow
Lower Lias.

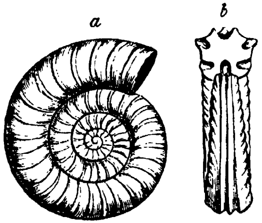
Fig. 374.



Leptæna Moorei, Dav.
Upper Lias, Ilminster.

Allusion has already been made (p. 341) to numerous zones in the Lias having each their peculiar Ammonites. Two of these occur near the base of the Lower Lias having a united thickness, varying from 40 to 80 feet. The upper of these is characterised by *Ammonites Bucklandi*, and the lower by *Ammonites Planorbis* (see figs. 375, 376).[1] Sometimes, however, there is a third intermediate zone, that of *Ammonites Angulatus*, which is the equivalent of the zone called the infra-lias on the Continent, the species of which are for the most part common to the superior group marked by *A Bucklandi*.

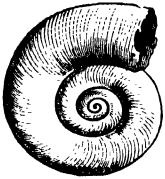
Fig. 375.



Ammonites Bucklandi, Sow.
,, *bisulcatus*, Brug.
⅛ diameter of original.

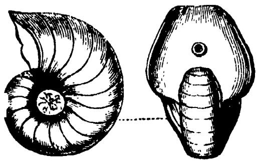
a. Side view. *b*. Front view, showing mouth and bisulcated keel. Characteristic of the lower part of the Lias of England and the Continent.

Fig. 376.



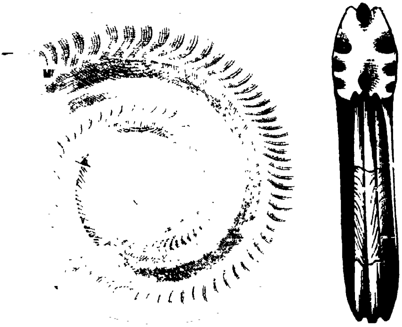
A. Planorbis, Sow.
½ diameter of original.
From the base of the Lower Lias of England and the Continent.

Fig. 377.



Nautilus truncatus, Sow.
Lias. ⅙ nat. size.

Fig. 378.



Ammonites bifrons, Brug. *A. Walcotii*, Sow.
Upper Lias shales.

Among the Crinoids or Stone-lilies of the Lias, the Pentacrinites are conspicuous (see fig. 380). Of *Palæocoma* (*Ophioderma*) *tenuibrachiata* (fig. 381), referable to the *Ophiuridæ* of Muller, perfect specimens have been met with in the Middle Lias beds of Dorset and Yorkshire.

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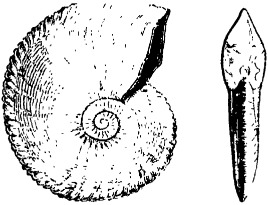
[1] Quart. Journ., vol. xvi. p. 376.

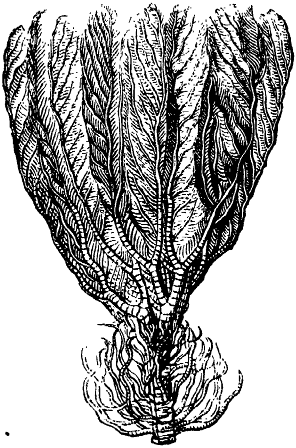
Fig. 379.



Ammonites margaritatus, Montf. Syn. *A. Stokesii*, Sow. *A. Clevelandicus*. Y. and B. Middle Lias.

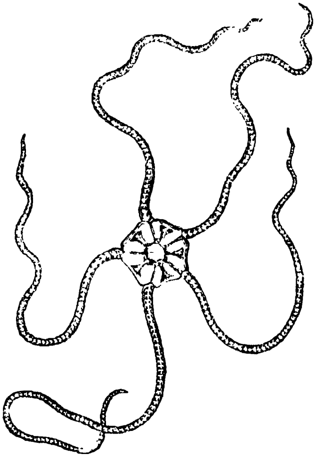
The *Extracrinus Briareus* (removed by Major Austin from *Pentacrinus* on account of generic differences) occurs in tangled masses, sometimes attached to floating wood or forming thin beds of considerable extent, in the Lower Lias of Dorset, Gloucestershire, and Yorkshire. The remains are often highly charged with pyrites. This Crinoid, with its innumerable tentacular arms, appears to have been frequently attached to the driftwood of the liassic sea, in the same manner as Barnacles float about on wood at the present day. There is another species of *Extracrinus* and several of *Pentacrinus* in the Lias; and the latter genus is found in nearly all the formations from the Lias to the London Clay

Fig. 380.



Extracrinus (*Pentacrinus*) *Briareus*. Miller. ¼ natural size. (Body, arms, and part of stem.) Lower Lias, Lyme Regis.

Fig. 381.

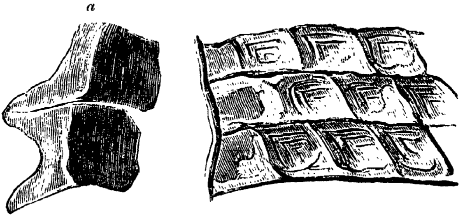


Palæocoma (*Ophioderma*) *tenuibrachiata*, E. Forbes. Middle Lias, Seatown, Dorset.

inclusive. It is represented in the present seas by the delicate and rare *Pentacrinus caput-medusæ* of the Antilles, which, with Comatula, is one of the few surviving members of the ancient family of the Crinoids, represented by so many extinct genera in the older formations. In 1870 Mr. Gwyn Jeffreys dredged up a new living species of Pentacrinus from a depth of 6,570 feet off the coast of Portugal, to which he gave the name of *P. Wyville-Thomsoni.*[1]

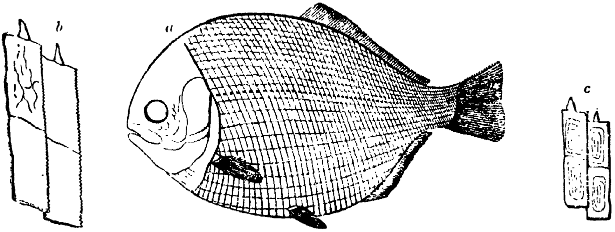
Fishes of the Lias.—The fossil fish, of which there are no less than 120 species known as British, resemble generically those of the Oolite, but differ, according to M. Agassiz, from those of the Cretaceous period. Among them is a species of *Lepidotus* (*L. gigas*, Agass.), fig. 382, which is found in the Lias of England, France, and Germany.[2] This genus was before mentioned (p. 301) as occurring in the Wealden, and is supposed to have frequented both rivers and sea-coasts. Another genus

Fig. 382.



Scales of *Lepidotus gigas*, Agass.
a. Two of the scales detached.

Fig. 383.



Scales of *Æchmodus Leachii.*

a. Æchmodus. Restored outline.

c. Scales of *Dapedius monilifer.*

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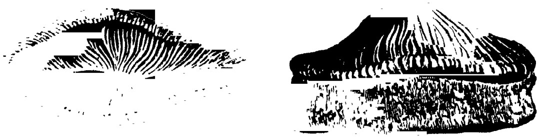
[1] Wyville Thomson, Depths of the Sea, p. 442.

[2] Agassiz, Poissons Fossiles, vol. ii. tab. 28, 29.

of Ganoids (fish possessing hard, shining, and enamelled scales), called *Æchmodus* (fig. 383), is almost exclusively Liassic. The teeth of a species of *Acrodus*, also, are very abundant in the Lower Lias (fig. 384).

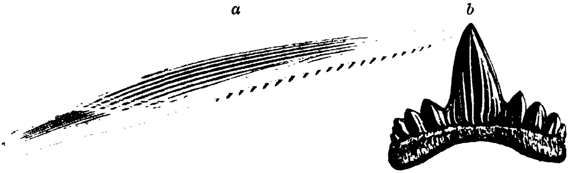
Fig. 384.



Acrodus nobilis, Agass. (tooth) ; commonly called 'fossil leech.'
Lias, Lyme Regis and Germany.

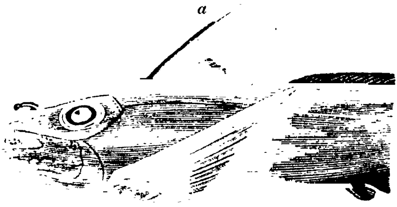
But the remains of fish which have excited more attention than any others are those large bony spines called *ichthyodorulites* (*a*, fig. 385), once supposed by some naturalists to be jaws, and by others weapons, resembling those of the living *Balistes* and *Silurus* ; but which M. Agassiz has shown to be neither the one nor the other. The spines, in the genera last mentioned, articulate with the backbone, whereas there are no signs of any such articulation in the ichthyodorulites. These last appear to

Fig. 385.



Hybodus reticulatus, Agass. Lias, Lyme Regis.
a. Part of fin, commonly called Ichthyodorulite. *b.* Tooth.

Fig. 386.



Chimæra monstrosa.[1]
a. Spine forming anterior part of the dorsal fin.

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[1] Agassiz, Poissons Fossiles, vol. iii., tab. C., fig. 1.

have been bony spines which formed the anterior part of the dorsal fin, like that of the living genera *Cestracion* and *Chimæra* (see *a*, fig. 386). In both of these genera, the posterior concave face is armed with small spines, as in that of the fossil *Hybodus* (fig. 385), a placoid fish of the shark family found fossil at Lyme Regis. Such spines are simply imbedded in the flesh, and attached to strong muscles. 'They serve,' says Dr. Buckland, 'as in the *Chimæra* (fig. 386), to raise and depress the fin, their action resembling that of a movable mast, raising and lowering backwards the sail of a barge.'[1]

Reptiles of the Lias.—It is not, however, the fossil fish which form the most striking feature in the organic remains of the Lias; but the *Enaliosaurian* reptiles (*Ichthyopterygia* and *Sauropterygia*), which are extraordinary for their number, size, and structure. Among the most singular of these are several species of *Ichthyosauri* and *Plesiosauri* (figs. 387, 388, p. 348). These genera are not confined to this formation, but have been found in strata as high as the White Chalk of England, and as low as the Trias of Germany, a formation which immediately succeeds the Lias in the descending order. It is evident from their fish-like vertebræ, their paddles, resembling those of a porpoise or whale, the length of their tail, and other parts of their structure, that the Ichthyosaurs were aquatic. Their jaws and teeth show that they were carnivorous; and the half-digested remains of fishes and reptiles, found within their skeletons, indicate the precise nature of their food.

Mr. Conybeare was enabled, in 1824, after examining many skeletons nearly perfect, to give an ideal restoration of the osteology of this genus, and of that of the *Plesiosaurus*.[2] (See figs. 387, 388.) The latter animal had an extremely long neck and small head, with teeth like those of the crocodile, and paddles analogous to those of the *Ichthyosaurus*, but larger. It is supposed to have lived in shallow seas and estuaries, and to have breathed air like the Ichthyosaur and our modern cetacea.[3] Some of the reptiles above mentioned were of formidable dimensions. One skeleton of *Ichthyosaurus platyodon*, from the Lias at Lyme, now in the British Museum, must have belonged to an animal more than 24 feet in length; and there are species of *Plesiosaurus* which measure from 18 to 20 feet in length. The form of the *Ichthyosaurus* may have fitted it to cut through the waves like the porpoise; as it was furnished besides its paddles with a tail-fin so constructed as to be a powerful organ of motion; but it is supposed that the *Plesiosaurus*, at least the long-necked species (fig. 388), was better suited to fish in shallow creeks and bays defended from heavy breakers.

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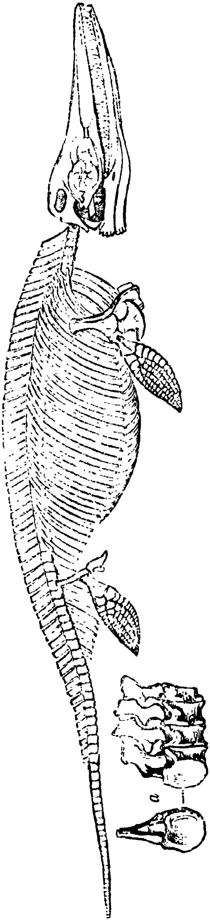
[1] Bridgewater Treatise, p. 290.

[2] Geol. Soc. Transactions, Second Series, vol. i. p. 49.

[3] Conybeare and De la Beche, Geol. Trans. First Series, vol. v. p. 559; and Buckland, Bridgew. Treat., p. 203.

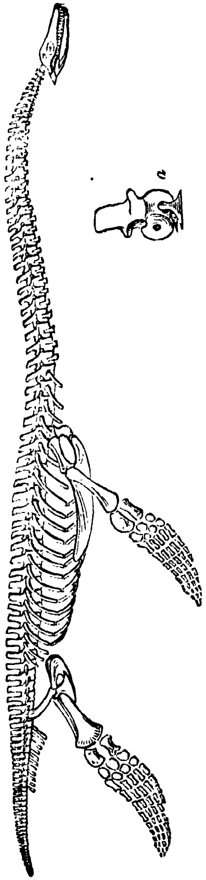
Fig. 387.



Skeleton of *Ichthyosaurus communis*, restored by Conybeare and Cuvier.

a. Costal vertebræ.

Fig. 388.



Skeleton of *Plesiosaurus dolichodeirus*, restored by Rev. W. D. Conybeare.

a. Cervical vertebræ.

It is now very generally agreed that these extinct saurians must have inhabited the sea: and it was urged that as there are now chelonians, like the tortoise, living in fresh water, and others, as the turtle, frequenting the ocean, so there may have been formerly some saurians proper to salt, others to fresh, water. The common crocodile of the Ganges is well known to frequent equally that river and the brackish and salt water near its mouth; and crocodiles are said in like manner to be abundant both in the rivers of the Isla de Pinos (or Isle of Pines), south of Cuba, and in the open sea round the coast. In 1835 a curious lizard (*Amblyrhynchus cristatus*) was discovered by Mr. Darwin in the Galapagos Islands.[1] It was found to be exclusively marine, swimming easily by means of its flattened tail, and subsisting chiefly on seaweed. One of them was sunk from the ship by a heavy weight, and on being drawn up after an hour was quite unharmed.

The families of Dinosauria, crocodiles and Pterosauria or winged reptiles, are also represented in the Lias.

Sudden destruction of Saurians.—It has been remarked, and truly, that many of the fish and saurians, found fossil in the Lias, must have met with sudden death and immediate burial; and that the destructive operation, whatever may have been its nature, was often repeated.

'Sometimes,' says Dr. Buckland, 'scarcely a single bone or scale has been removed from the place it occupied during life; which could not have happened had the uncovered bodies of these saurians been left, even for a few hours, exposed to putrefaction, and to the attacks of fishes and other smaller animals at the bottom of the sea.'[2] Not only are the skeletons of the Ichthyosaurs entire, but sometimes the contents of their stomachs still remain between their ribs, as before remarked, so that we can discover the form of their excrements and the particular species of fish on which they lived. Not unfrequently there are layers of these coprolites, at different depths in the Lias, at a distance from any entire skeletons of the marine lizards from which they were derived; 'as if,' says Sir H. de la Beche, the muddy bottom of the sea received small sudden accessions of matter from time to time, covering up the coprolites and other exuviæ which had accumulated during the intervals.'[3] It is further stated that, at Lyme Regis, those surfaces only of the coprolites which lay uppermost at the bottom of the sea have suffered partial decay, from the action of water before they were covered and protected by the muddy sediment that has afterwards permanently enveloped them.

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[1] See Darwin, Naturalist's Voyage, p. 385. Murray.

[2] Bridgewater Treatise, p. 115.

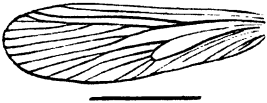
[3] Geological Researches, p. 334.

Numerous specimens of the Calamary or pen-and-ink fish (*Geoteuthis Bollensis*) have also been met with in the Lower Lias at Lyme, with the ink-bags still distended, containing the ink in a dried state, chiefly composed of carbon, and but slightly impregnated with carbonate of lime. These dibranchiate cephalopoda, therefore, must, like the saurians, have been soon buried in sediment; for, if long exposed after death, the membrane containing the ink would have decayed.[1]

As we know that river-fish are sometimes stifled, even in their own element, by muddy water during floods, it cannot be doubted that the periodical discharge of large bodies of turbid fresh water into the sea may be still more fatal to marine tribes. In the 'Principles of Geology' I have shown that large quantities of mud and drowned animals have been swept down into the sea by rivers during earthquakes, as in Java in 1699; and that indescribable multitudes of dead fishes have been seen floating on the sea after a discharge of noxious vapours during similar convulsions. But in the intervals between such catastrophes, strata may have accumulated slowly in the sea of the Lias, some being formed chiefly of one description of shell, such as ammonites, others of gryphites.

Freshwater deposits—Insect-beds.—From the above remarks the reader will infer that the Lias is for the most part a marine deposit. Some members, however, of the series have an estuarine character, and must have been formed within the influence of rivers. At the base of the Upper and Lower Lias respectively, insect-beds appear to be almost everywhere present, throughout the Midland and South-western districts of England. These beds are crowded with the remains of insects, small fish, and crustaceans, with occasional marine shells. One band in Gloucestershire, rarely exceeding a foot in thickness, has been named the 'insect limestone.' It passes upwards, says the Rev. P. B. Brodie,[2] into a shale containing *Cypris* and *Estheria*, and is full of the wing-cases of several genera of coleoptera, with some nearly entire beetles, of which the eyes are preserved. The nervures of the wings of neurop-

Fig. 389.



nat. size.

Wing of a neuropterous insect, from the Lower Lias, Gloucestershire. (Rev. P. B. Brodie.)

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[1] Buckland, Bridgew. Treat., p. 307.

[2] A History of Fossil Insects, &c., 1846. London.

terous insects (fig. 389) are beautifully perfect in this bed. Ferns, with cycads and leaves of monocotyledonous plants, and some apparently brackish and freshwater shells, accompany the insects in several places, while in others marine shells predominate, the fossils varying apparently as we examine the bed nearer or farther from the ancient land, or the source whence the fresh water was derived. After studying 300 specimens of these insects from the Lias, Mr. Westwood declares that they comprise both wood-eating and herb-devouring beetles, of the Linnean genera *Elater*, *Carabus*, &c., besides grasshoppers (*Gryllus*), and detached wings of dragon-flies and may-flies, or insects referable to the Linnæan genera *Libellula*, *Ephemera*, *Hemerobius*, and *Panorpa*, in all belonging to no less than twenty-four families. The size of the species is usually small, and such as taken alone would imply a temperate climate ; but many of the associated organic remains of other classes must lead to a different conclusion. At Schambelen, in the canton of Argovie in Switzerland, a rich liassic insect fauna has been brought to light agreeing in general character with the insect-beds of England, but comprising nearly three times the number of species in a very perfect state.[1]

Fossil plants.—Among the vegetable remains of the Lias, several species of *Zamia* have been found at Lyme Regis, and the remains of coniferous plants at Whitby. M. Ad. Brongniart enumerates forty-seven liassic acrogens, most of them ferns ; and fifty gymnosperms, of which thirty-nine are cycads, and eleven conifers. Among the cycads the predominance of *Zamites*, and among the ferns the numerous genera with leaves having reticulated veins (as in fig. 357, p. 337), are mentioned as botanical characteristics of this era.[2] The absence as yet from the Lias and Oolite of all signs of dicotyledonous angiosperms is worthy of notice. The leaves of such plants are frequent in tertiary strata, and occur in the Cretaceous, though less plentifully (see above, p. 287). The angiosperms seem, therefore, to have been, at the least, comparatively rare in these older secondary periods, when more space was occupied by the cycads and conifers.

Origin of the Oolite and Lias.—The entire group of Oolite and Lias consists of repeated alternations of clay, sandstone, and limestone, following each other in the same order. Thus the clays of the Lias are in ascending order followed by the sands now considered as belonging to the same formation (see p. 340), though formerly referred to the Inferior Oolite, and these sands again by the shelly and Pisolitic beds of the Inferior Oolite, succeeded by the limestone called the Great or Bath Oolite. So, in the Middle Oolite, the Oxford clay is followed by calcareous grit and coral rag; lastly, in the Upper Oolite, the Kimmeridge clay is followed by the Portland sand and limestone (see fig. 304, p. 308).[1] The clay beds, however, as Sir H. D. de la Beche remarks, can be followed over larger areas than the sand or sandstones.[2] It should also be remembered that while the Oolite system becomes arenaceous and resembles a coal-field in Yorkshire, it assumes in the Alps an almost purely calcareous form, the sands and clays being omitted. Nevertheless, in some districts the clays and intervening limestones do retain, in reality, a pretty uniform character for distances of from 400 to 600 miles from east to west and north to south.

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[1] For causes of the fossilisation of insects, see p. 200.

[2] Tableau des Vég. Foss., 1849, p. 105

In order to account for such a succession of events, we may imagine the bed of the ocean to be at first the receptacle for ages of fine argillaceous sediment, brought by oceanic currents, which may have communicated with rivers, or with part of the sea near a wasting coast. This mud ceases, at length, to be conveyed to the same region, either because the land which had previously suffered denudation is depressed and submerged, or because the current is deflected in another direction by the altered shape of the bed of the ocean and neighbouring dry land. By such changes the water becomes once more clear and fit for the growth of stony zoophytes. Calcareous sand is then formed from comminuted shell and coral, or, in some cases, arenaceous matter replaces the clay; because it commonly happens that the finer sediment, being first drifted farthest from coasts, is subsequently overspread by coarse sand, after the sea has grown shallower, or when the land increasing in extent, whether by upheaval or by sediment filling up parts of the sea, has approached nearer to the spots first occupied by fine mud.

The increased thickness of the limestones in those regions, as in the Alps and Jura, where the clays are comparatively thin, arises from the calcareous matter having been derived from species of corals and other organic beings which live in clear water, far from land, to the growth of which the influx of mud would be unfavourable. Portions, therefore, of these clays and limestones have probably been formed contemporaneously to a greater extent than we can generally prove, for the distinctness of the species of organic beings would be caused by the difference of conditions between the more littoral and the more pelagic areas and the different depths and nature of the sea-bottom. Independently of those ascending and descending movements which have given rise to the superposition of the limestones and clays, and by which the position of land and sea are made in the course of ages to vary, the geologist has the difficult task of allowing for the contemporaneous thinning out in one direction and thickening in another of the successive organic and inorganic deposits of the same era.

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[1] Conybeare and Philips' Outlines, &c., p. 166. [2] Geol. Researches, p. 337.

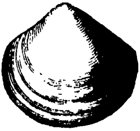
CHAPTER XXI.

TRIAS, OR NEW RED SANDSTONE GROUP.

Beds of passage between the Lias and Trias, Rhætic beds—Triassic mammifer—Triple division of the Trias—Keuper, or Upper Trias of England—Reptiles of the Upper Trias—Footprints in the Bunter formation in England—Dolomitic conglomerate of Bristol—Origin of Red Sandstone and Rock-salt—Precipitation of salt from inland lakes and lagoons—Trias of Germany—Keuper—St. Cassian and Hallstadt beds—Peculiarity of their fauna—Muschelkalk and its fossils—Trias of the United States—Fossil footprints of birds and reptiles in the valley of the Connecticut—Triassic mammifer of North Carolina—Triassic coal-field of Richmond, Virginia—Low grade of early mammals favourable to the theory of progressive development.

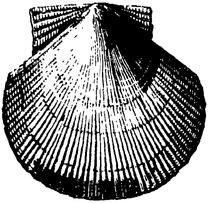
Beds of passage between the Lias and Trias—Rhætic beds.—We have mentioned in the last chapter (p. 343) that the base of the Lower Lias is characterised, both in England and Germany, by beds containing distinct species of Ammonites, the lowest subdivision having been called the zone of *Ammonites Planorbis.* Below this zone, on the boundary line between the Lias and the strata of which we are about to treat, called 'Trias,' certain cream-coloured limestones are usually found in the West and South of England. These white beds were called by William Smith the White Lias, and they have been shown by Mr. Charles Moore to belong to a formation similar to one in the Rhætian Alps of Bavaria, to which M. Gümbel has applied the name of Rhætic. They have also long been known as the Koessen beds in Germany, and may be regarded as beds of passage between

Fig. 390.



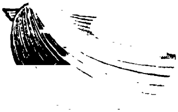
Cardium rhæticum, Merrian. Nat. size. Rhætic Beds.

Fig. 391.



Pecten Valoniensis, Dfr. ½ nat. size. Portrush, Ireland, &c. Rhætic Beds.

Fig. 392.



Avicula contorta, Portlock. Portrush, Ireland, &c. Nat. size. Rhætic Beds.

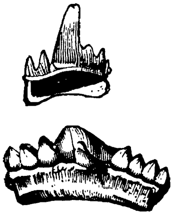
the Lias and Trias. They are named the Penarth beds by the Government surveyors of Great Britain, from Penarth, near Cardiff, in Glamorganshire, where they attain a thickness of fifty feet.

The principal member of this group has been called by Dr. Wright the *Avicula contorta* bed,[1] as this shell is very abundant, and has a wide range in Europe. General Portlock first described the formation as it occurs at Stradneagh near Portrush, in Antrim, where the *Avicula contorta* (fig. 392) is accompanied by *Pecten Valoniensis* (fig. 391) as in Germany.

The best known member of the group, a thin band or bone-breccia, is conspicuous among the black shales in the neighbourhood of Axmouth in Devonshire, and in the cliffs of Westbury-on-Severn, as well as at Aust and other places on the borders of the Bristol Channel. It abounds in the remains of saurians and fish, and was formerly classed as the lowest bed of the Lias; but Sir P. Egerton first pointed out, in 1841, that it should be referred to the Upper New Red Sandstone, because it contained an assemblage of fossil fish which are either peculiar to this stratum, or belong to species well known in the Muschelkalk of Germany. These fish belong to the genera *Acrodus*, *Hybodus*, *Gyrolepis*, and *Saurichthys*.

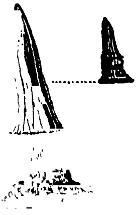
Among those common to the English bone-bed and the Muschelkalk of Germany are *Hybodus plicatilis* (fig. 393), *Saurichthys apicalis* (fig. 394), *Gyrolepis tenuistriatus* (fig. 395), and *G. Albertii*. Remains of saurians, *Plesiosaurus* among others, have also been found in the bone-bed, and plates of an *Encrinus*. It may be questioned whether some of those fossils which have the most Triassic character may not have been derived from the

Fig. 393.



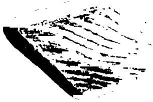
Hybodus plicatilis, Agass. Teeth, Bone-bed, Aust and Axmouth.

Fig. 394.



Saurichthys apicalis, Agass. Tooth; natural size and magnified. Axmouth.

Fig. 395.



Gyrolepis tenuistriatus, Agass. Scale; nat. size and magnified Axmouth.

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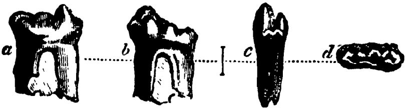
[1] Dr. Wright, on Lias and Bone Bed, Quart. Geol. Journ. 1860, vol. xvi.

destruction of older strata, since in bone beds, in general, many of the organic remains are undoubtedly derivative.

Triassic mammifer.—In North-western Germany, as in England, there occurs beneath the Lias a remarkable bone breccia. It is filled with shells and with the remains of fishes and reptiles, almost all the genera of which, and some even of the species, agree with those of the subjacent Trias. This breccia has accordingly been considered by Professor Quenstedt and other German geologists of high authority, as the newest or uppermost part of the Trias. Professor Plieninger found in it, in 1847, at Diegerloch, about two miles to the south-east of Stuttgart, the molar tooth of a small Triassic mammifer, called by him *Microlestes antiquus.* He inferred its true nature from its double fangs, and from the form and number of the protuberances or cusps on the flat crown; and considering it as predaceous, probably insectivorous, he called it *Microlestes* from *μικρος*, little, and *ληστης*, a beast of prey. Soon afterwards he found a second tooth, also at the same locality.

Fig. 396.



Microlestes antiquus, Plieninger. Molar tooth, magnified. Upper Trias. Diegerloch, near Stuttgart, Würtemberg.

a. View of inner side? *b.* Same, outer side?
c. Same in profile. *d.* Crown of same.

No anatomist had been able to give any feasible conjecture as to the affinities of this minute quadruped until Dr. Falconer, in 1857, recognised an unmistakeable resemblance between its teeth and the two black molars of his new genus *Plagiaulax* (fig. 312, p. 313), from the Purbeck strata. This would lead us to the conclusion that Microlestes was marsupial and plant-eating.

In Würtemburg there are two bone-beds, namely, that containing the Microlestes, which has just been described, which constitutes, as we have seen, the uppermost member of the Trias; and another of still greater extent, and still more rich in the remains of fish and reptiles, which is of older date, intervening between the Keuper and Muschelkalk.

The genera *Saurichthys*, *Hybodus*, and *Gyrolepis* are found in both these breccias, and one of the species, *Saurichthys Mongeoti*, is common to both bone-beds, as is also a remarkable reptile called *Nothosaurus mirabilis.* The saurian called *Belodon* by H. Von Meyer, of the Thecodont family, is another Triassic form, associated at Diegerloch with Microlestes.

TRIAS OF ENGLAND.

Beneath the Lias in the midland and western counties of England, there is a great series of red loams, shales, sandstones, and conglomerates, to which the name of the 'New Red Sandstone formation' was first given to distinguish it from other shales and sandstones called the 'Old Red,' often identical in mineral character, but differing greatly in age, being of earlier date than the Permian and Carboniferous formations. The name of 'Red Marl' has been incorrectly applied to the red clays of this formation, as before explained (p. 14), for they are remarkably free from calcareous matter. The absence, indeed, of carbonate of lime, as well as the scarcity of organic remains, together with the bright red colour of most of the rocks of this group, causes a strong contrast between it and the Jurassic formations before described.

The group in question is more fully developed in Germany than in England or France. It has been called the Trias by German writers, or the Triple Group, because it is separable into three distinct formations, called the 'Keuper,' the 'Muschelkalk,' and the 'Bunter-sandstein.' Of these the middle division, or the Muschelkalk, is wholly wanting in England, and the uppermost (Keuper) and lowest (Bunter) members of the series are not rich in fossils.

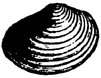
Upper Trias, or Keuper.—In certain grey indurated marls below the bone-bed at Watchet, on the coast of Somersetshire, Mr. Boyd Dawkins has found a molar tooth of Microlestes, enabling him to refer to the Trias, strata formerly classed with the Lias. Mr. Charles Moore had previously discovered many teeth of the same mammifer near Frome, in Somersetshire, in the contents of a vertical vein or fissure traversing a mass of carboniferous limestone. The top of this fissure must have communicated with the bed of the Triassic sea, and probably at a point not far from the ancient shore on which the small marsupials of that era abounded.

This upper division of the Trias called the Keuper is of great thickness in the central counties of England, attaining, according to Mr. Hull's estimate, no less than 3,450 feet in Cheshire, and it covers a large extent of country between Lancashire and Devonshire.

In Worcestershire and Warwickshire in sandstone belonging to the uppermost part of the Keuper the bivalve crustacean

Estheria minuta occurs. The member of the English 'New Red' containing this shell, in those parts of England, is, according to Sir Roderick Murchison and Mr. Strickland, 600 feet thick, and consists chiefly of red marl or slate, with a band of sandstone. Icthyodorulites, or spines of *Hybodus*, teeth of fishes, and footprints of reptiles were observed by the same geologists in these strata.

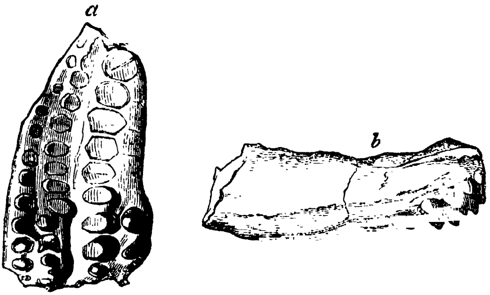
Fig. 397.



Estheria minuta, Bronn.

In the Upper Trias or Keuper the remains of four saurians have been found. The one called *Rhynchosaurus* occurred at Grinsell near Shrewsbury, and is characterised by having a small bird-like skull and jaws without teeth. The other three, *Stagonolepis*, *Telerpeton*, and *Hyperodapedon*, were brought to light near Elgin, in strata formerly supposed to belong to the Old Red Sandstone, but now recognised as Upper Triassic.[1] The *Hyperodapedon* was afterwards discovered in beds of about the same age in the neighbourhood of Warwick, and also in South Devon, and remains of the same genus have been found both in Central India and Southern Africa in rocks believed to be of Triassic age. It has been shown by Professor Huxley to be a terrestrial reptile having numerous palatal teeth, and closely allied to the living Sphenodon of New Zealand.

Fig. 398.



Hyperodapedon Gordoni. Left Palate, Maxillary.
(Showing the two rows of palatal teeth on opposite sides of the jaw.
a. Under surface. *b.* Exterior right side.

The recent discovery of a living saurian in New Zealand so closely allied to this supposed extinct division of the Lacertilia seems to afford an illustration of a principle pointed out by Mr. Darwin of the survival in insulated tracts, after many changes in physical geography, of orders of which the congeners have become extinct on continents where they have been exposed to the severer competition of a larger progressive fauna.

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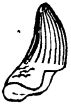
[1] See Judd, Quart. Geol. Journ., vol. xxix. p. 142, 1873.

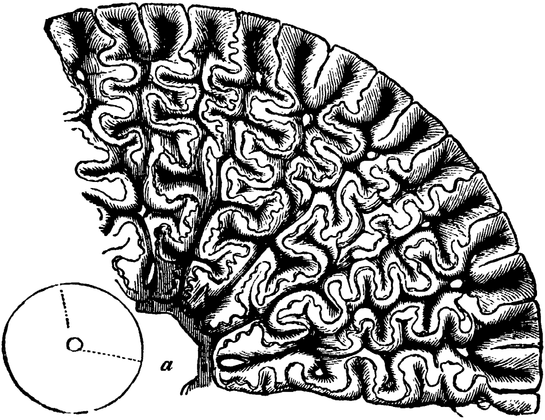
In 1842 Professor Owen examined microscopically some teeth of *Labyrinthodon* (fig. 399) from the Keuper in Warwickshire and discovered in them a structure of extraordinary complexity.[1] The dentinal wall was found to be disposed in many vertical folds, every alternate fold being several times plaited transversely. A cross section of one of these exhibits a series of convolutions, resembling the labyrinthic windings of the surface of the brain, and from this character Professor Owen has proposed the name *Labyrinthodon* for the new genus. The annexed representation (fig. 400) of part of one is given from his 'Odontography,' plate 64 A. The entire length of this tooth is supposed to have been about three inches and a half, and the breadth at the base one inch and a half.

Fig. 399.



Tooth of *Labyrinth* , nat. size. W k sandstone.

Fig. 400.



Transverse section of upper part of tooth of *Labyrinthodon Jaegeri*, Owen (*Mastodonsaurus Jaegeri*, Meyer); natural size, and a segment magnified.
a. Pulp cavity, from which the processes of pulp and dentine radiate.

This remarkable structure proved on comparison to characterise not only the genus *Labyrinthodon* but also the allied genus *Mastodonsaurus* of the German Keuper, described p. 365. The

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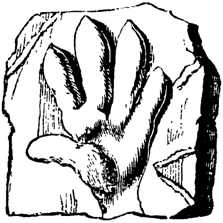
[1] Trans. Geol. Soc., 2nd series vol. vi. pl. 2.

Labyrinthodonts now constitute a somewhat extensive order of Amphibia of gigantic dimensions in comparison with any representatives of the class now living.

The basement beds of the Keuper rest with a slight unconformability upon an eroded surface of the 'Bunter' next to be described. In these basement beds Professor W. C. Williamson has described the footprints of a *Cheirotherium* similar to those presently to be mentioned in the Bunter beds, but peculiar in exhibiting a scaly structure.[1]

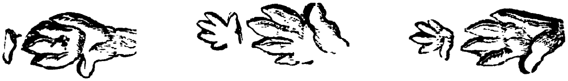
Lower Trias, or Bunter.—The lower division or English representative of the 'Bunter' attains, according to Professor Ramsay, a thickness of 1,500 feet in the counties last mentioned. Besides red and green shales and red sandstones, it comprises much soft white quartzose sandstone, in which the trunks of silicified trees have been met with at Allesley Hill, near Coventry. Several of them were a foot and a half in diameter, and some yards in length, decidedly of coniferous wood, and showing rings of annual growth.[2] Impressions, also, of the footsteps of animals have been detected in Lancashire and Cheshire in this formation. Some of the most remarkable occur a few miles from Liverpool, in the whitish quartzose sandstone of Storton Hill, on the Cheshire side of the Mersey. They bear a close resemblance to tracks first observed in this member of the Upper New Red Sandstone, at the village of Hesseberg, near Hildburghausen, in Saxony. For many years these footprints have been referred to a large unknown quadruped, provisionally named *Cheirotherium* by Professor Kaup, because the marks both of the fore and hind feet resembled impressions made by a human hand (see fig. 401). The footmarks at Hesseberg are partly

Fig. 401.



Single footstep of *Cheirotherium*. Bunter-sandstein, Saxony. One-eighth of natural size.

Fig. 402.



Line of footsteps on slab of sandstone. Hildburghausen, in Saxony.

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[1] Quart. Geol. Journ., vol. xxiii. 1867, p. 56.

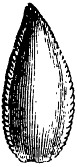
[2] Buckland, Proc. Geol. Soc., vol. ii. p. 439; and Murchison and Strickland, Geol. Trans. Second Ser., vol. v. p. 347.

concave, and partly in relief, the former, or the depressions, are seen upon the upper surface of the sandstone slabs, but those in relief are only upon the lower surfaces, being in fact natural casts, formed in the subjacent footprints as in moulds. The larger impressions, which seem to be those of the hind foot, are generally 8 inches in length, and 5 in width, and one was 12 inches long. Near each large footstep, and at a regular distance (about an inch and a half), before it, a smaller print of a fore foot, 4 inches long and 3 inches wide, occurs. The footsteps follow each other in pairs, each pair in the same line, at intervals of 14 inches from pair to pair. The large as well as the small steps show the great toes alternately on the right and left side ; each step makes the print of five toes, the first or great toe being bent inwards like a thumb. Though the fore and hind foot differ so much in size, they are nearly similar in form.

As neither in Germany nor in England had any bones or teeth been met with in the same identical strata as the footsteps, anatomists indulged, for several years, in various conjectures respecting the mysterious animals from which they might have been derived. Professor Kaup suggested that the unknown quadruped might have been allied to the *Marsupialia* ; for in the kangaroo the first toe of the fore foot is in a similar manner set obliquely to the others, like a thumb, and the disproportion between the fore and hind feet is also very great. But M. Link conceived that some of the four species of animals of which the tracks had been found in Saxony might have been gigantic *Batrachians* ; and when it was afterwards inferred that the Labyrinthodon was an air-breathing reptile it was conjectured by Professor Owen that it might be one and the same as the Cheirotherium.

Dolomitic Conglomerate of Bristol.—Near Bristol, in Somersetshire, and in other counties bordering the Severn, the lowest strata belonging to the Triassic series consist of a conglomerate or breccia resting unconformably upon the Old Red Sandstone, and on different members of the Carboniferous rocks such as the Coal Measures, Millstone Grit, and Mountain Limestone. This mode of superposition will be understood by reference to the section below Dundry Hill (fig. 85, p. 107), where No. 4 is the dolomitic conglomerate. Such breccias may have been partly the result of the subaërial waste of an old land-surface which gradually sank down and suffered littoral denudation in proportion as it became submerged. The pebbles and fragments of older rocks which constitute the conglomerate are cemented together by a red or yellow base of dolomite, and in some places the encrinites, corals, brachiopoda, and other fossils derived from the Mountain Limestone are so detached from the parent rocks that they have the deceptive appearance of belonging to a fauna contemporaneous with the dolomitic beds in which they occur. The imbedded fragments are both rounded and angular, some consisting of carboniferous limestone and millstone grit, being of vast size, and many weighing nearly a ton. Fractured bones and teeth of saurians which are truly of contemporaneous origin, have been found in the lower part of the breccia, and two of these, called *Thecodontosaurus* and *Palæosaurus*, from the manner in which the teeth were implanted in the jawbone, obtained great celebrity because the patches of red conglomerate in which they were found, at Durdham Down, near Bristol, were originally supposed to be of Permian or Palæozoic age, and therefore the only representatives in England of vertebrate animals of so high a type in rocks of such antiquity. The teeth of these saurians are conical, compressed, and with finely serrated edges (see fig. 403); they are referred by Professor Huxley to the Dinosauria.

Fig. 403.



Tooth of *Thecodontosaurus*; 3 times magnified, Riley and Stutchbury. Dolomitic conglomerate. Durdham Down, near Bristol.

Origin of Red Sandstone and Rock Salt.—In Cheshire and Lancashire there are red clays containing gypsum and salt of the age of the Trias which are between 1,000 and 1,500 feet thick. In some places lenticular masses of pure rock salt nearly 100 feet thick are interpolated between the argillaceous beds. At the base of the formation beneath the rock salt occur the Lower Sandstones and Marl, called provincially in Cheshire ‘water-stones,’ which are largely quarried for building. They are often ripple-marked, and are impressed with numerous footprints of reptiles.

As in various parts of the world red and mottled clays and sandstones, of several distinct geological epochs, are found associated with salt, gypsum, and magnesian limestone, or with one or all of these substances, there is, in all likelihood, a general cause for such a coincidence. Nevertheless, we must not forget that there are dense masses of red and variegated sandstones and clays, thousands of feet in thickness, and of vast horizontal extent, wholly devoid of saliferous or gypseous matter. There are also deposits of gypsum and of common salt, as in the blue clay formation of Sicily, without any accompanying red sandstone or red clay.

These red deposits may be accounted for by the decomposition of gneiss and mica schist, which in the eastern Grampians of Scotland has produced a mass of detritus of precisely the same colour as the Old Red Sandstone.

It is a general fact, and one not yet accounted for, that scarcely any fossil remains are ever preserved in stratified rocks in which this oxide of iron abounds; and when we find fossils in the New or Old Red Sandstone in England, it is in the gray, and usually calcareous beds, that they occur. The saline or gypseous interstratified beds may have been produced by submarine gaseous emanations, or hot mineral springs which often continue to flow in the same spots for ages. Beds of rock salt are, however, more generally attributed to the evaporation of lakes or lagoons communicating at intervals with the ocean. In Cheshire two beds of salt occur of the extraordinary thickness of 90 or even 100 feet, and extending over an area supposed to be 150 miles in diameter. The adjacent beds present ripple-marked sandstones and footprints of animals at so many levels as to imply that the whole area underwent a slow and gradual depression during the formation of the red sandstone. Professor Ramsay has remarked in regard to the Trias that it was probably a Continental Period with many inland lakes and seas, the Keuper marls of the British Isles having been deposited in a great lake, fresh or brackish, at the beginning and afterwards rendered salt by evaporation. 'Were the rainfall,' he observes, 'of the area drained by the Jordan to increase gradually, the basin of the Dead Sea would by degrees fill with water, and successive deposits of sediment would gradually overlap each other on the shelving slopes of the lake-basin in which solid salts had previously been deposited. There are examples of this kind of overlap in the New Red Marl of England, in Somerset, Gloucester, Hereford, and Leicester.'[1] Professor Ramsay has pointed out that ferruginous mud and ores of iron are deposited in some of the lakes of Sweden at the present day. These are periodically dredged for economic purposes by the proprietors till the layer is exhausted, and after a sufficient interval they renew their dredging operations and new deposits are found. He therefore suggests that the red peroxide may in itself be an indication of lacustrine conditions, for each grain of sand and mud is encrusted with a thin pellicle of peroxide of iron, which he thinks could not have taken place in a wide and deep sea.[2] This theory of the Continental origin of the Trias derives some confirmation from the fact that the earliest terrestrial mammalia (*Microlestes*) yet discovered in Europe and America (see pp. 356, 373) are of Triassic date.

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[1] Quart. Geol. Journ., 1871, vol. xxvii., p. 196.

[2] Contemporary Review, July 1873, p. 201.

Major Harris, in his 'Highlands of Ethiopia,' describes a salt lake, called the Bahr Assal, near the Abyssinian frontier, which once formed the prolongation of the Gulf of Tadjara, but was afterwards cut off from the gulf by a broad bar of lava. 'Fed by no rivers, and exposed in a burning climate to the unmitigated rays of the sun, it has shrunk into an elliptical basin, seven miles in its transverse axis half filled with smooth water of the deepest cærulean hue, and half with a solid sheet of glittering snow-white salt, the offspring of evaporation.' 'If,' says Mr. Hugh Miller, 'we suppose, instead of a barrier of lava, that sand-bars were raised by the surf on a flat arenaceous coast during a slow and equable sinking of the surface, the waters of the outer gulf might occasionally topple over the bar, and supply fresh brine when the first stock had been exhausted by evaporation.'[1]

The Runn of Cutch, as I have shown elsewhere,[2] is a low region near the delta of the Indus, equal in extent to about a quarter of Ireland, which is neither land nor sea, being dry during part of every year, and covered by salt water during the monsoons. Here and there its surface is encrusted over with a layer of salt caused by the evaporation of sea water. A subsiding movement has been witnessed in this country during earthquakes, so that a great thickness of pure salt might result from a continuation of such sinking.

TRIAS OF GERMANY.

In Germany, as before hinted, p. 357, the Trias first received its name as a Triple Group, consisting of two sandstones with an intermediate marine calcareous formation, which last is wanting in England.

NOMENCLATURE OF TRIAS.

German	French	English
Keuper . .	Marnes irisées .	Saliferous and gypseous shales and sandstone.
Muschelkalk . .	Muschelkalk, ou calcaire coquillier .	wanting in England.
Bunter-Sandstein .	Grès bigarré . .	Sandstone and quartzose conglomerate.

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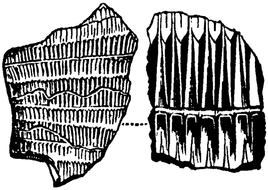
[1] Hugh Miller, First Impressions of England, 1847, pp. 183, 214.

[2] Principles of Geology, chap. xxvii.

Keuper.—The first of these, or the Keuper, underlying the beds before described as Rhætic, attains in Würtemberg a thickness of about 1,000 feet. It is divided by Alberti into sandstone, gypsum, and carbonaceous clay-slate.[1] In this formation, in the year 1828, Prof. Jaeger, of Stuttgart, found some gigantic conical teeth with vertically ribbed sides, to which he gave the name of *Mastodonsaurus*; and a fragment of a large skull, comprising two well-ossified occipital condyles, which was named Salamandroides. Prof. Jaeger regarded the former as a saurian, and the latter as an amphibian; but both have since been proved to belong to one genus, for which the name *Mastodonsaurus* has been retained.[2] Other remains of reptiles called *Nothosaurus* and *Phytosaurus*, have also been found, and the detached teeth of placoid fish of the genera *Saurichthys* and *Gyrolepis* (figs. 394, 395, p. 355). The plants of the Keuper are generically very analogous to those of the oolite and lias, consisting of ferns, equisetaceous plants, cycads, and conifers, with a few doubtful monocotyledons. A few species, among which is *Equisetum arenaceum*, are common to this group and the oolite.

Fig. 404.



Equisetum arenaceum. Fragment of stem, and a small portion of same magnified. Keuper.

St. Cassian and Hallstadt Beds (see map, fig. 405, p. 366).—The sandstones and clay of the Keuper afford, in the N.W. of Germany, as in France and England, but a scanty representation of the marine life of that period. We might, however, have anticipated, from its rich reptilian fauna, that the contemporaneous inhabitants of the sea of the Keuper period would be very numerous, should we ever have an opportunity of bringing their remains to light. This, it is believed, has at length been accomplished by the position now assigned to certain Alpine rocks called the 'St. Cassian beds,' the true place of which in the series was until lately a subject of much doubt and discussion. It has been proved that the Hallstadt beds on the northern flanks of the Austrian Alps correspond in age with the St. Cassian beds on their southern declivity, and the Austrian geologists, M. Suess of Vienna, and others, have satisfied themselves that the Hallstadt formation is referable to the period of the Upper Trias. Assuming this conclusion to be correct, we become acquainted suddenly and unexpectedly with a rich marine fauna belonging to a period previously supposed to be very barren of organic remains, because in England, France, and Northern Germany the Upper Trias is chiefly represented by beds of fresh or brackish water origin.

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[1] Monog. des Bunter-Sandsteins.

[2] Jaeger, Ueber die fossilen Reptilien von Würtemberg. Stuttgart, 1828.

Fig. 405.

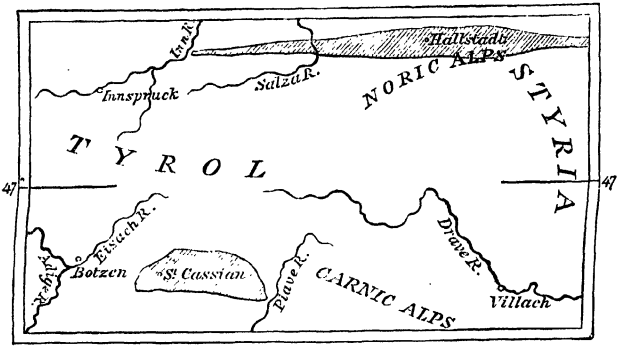
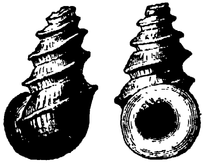
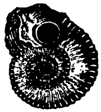


Fig. 406.



Scoliostoma, St. Cassian.

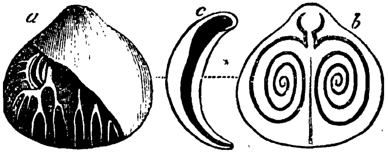
Fig. 407.



Platys'oma Suessii
Hörnes.
From Hallstadt.

About 600 species of invertebrate fossils occur in the Hallstadt and St. Cassian beds, many of which are still undescribed; some of the Mollusca are of new and peculiar genera, as *Scolio-*

Fig. 408.



Koninckia Leonhardi, Wissmann.

a. Ventral view. Part of ventral valve removed to show the vascular impressions of dorsal valve.
b. Interior of dorsal valve, showing spiral processes restored.
c. Vertical section of both valves. Part shaded black showing place occupied by the animal, and the dorsal valve following the curve of the ventral.

stoma (fig. 406) and *Platystoma* (fig. 407) among the Gasteropoda ; and *Koninckia* (fig. 408) among the Brachiopoda.

The following table of genera of marine shells from the Hallstadt and St Cassian beds, drawn up first on the joint authority of M. Suess and the late Dr. Woodward, and since corrected by Messrs. Etheridge and Tate, shows how many connecting links between the fauna of primary and secondary (Palæozoic and Mesozoic) rocks are supplied by the St. Cassian and Hallstadt beds.

GENERA OF FOSSIL MOLLUSCA IN THE ST. CASSIAN AFD HALLSTADT BEDS.

Common to Older Rocks	Characteristic Triassic Genera	Common to Newer Rocks
Orthoceras	Ceratites	Ammonites
Bactrites	Cochloceras	Chemnitzia
Machrocheilus	Choristoceras	Cerithium
Loxonema	Rhabdoceras	Monodonta
Holopella	Aulacoceras	Opis
Murchisonia	*Scoliostoma	Sphœra
	Naticella	Cardita
Porcellia	Platystoma	Myoconcha
Athyris	Ptychostoma	Hinnites
Retzia	Euchrysalis	Monotis
Cyrtina	Halobia	Plicatula
Euomphalus	Hörnesia	Pachyrisma
	Amphiclina	Thecidium
	Koninckia	
	**Cassianella	
	**Myophoria	

The first column marks the last appearance of several genera which are characteristic of Palæozoic strata. The second shows those genera which are characteristic of the Upper Trias, either as peculiar to it or, as in the three cases marked by asterisks, reaching their maximum of development at this era. The third column marks the first appearance in Triassic rocks of genera destined to become more abundant in later ages.

It is only, however, when we contemplate the number of species by which each of the above-mentioned genera are represented that we comprehend the peculiarities of what is commonly called the St. Cassian fauna. Thus, for example, the Ammonite, which is not common to older rocks, is represented by no less than seventy-three species; whereas Loxonema, which is only known as common to older rocks, furnishes fifteen Triassic species. Cerithium, so abundant in tertiary strata, and which still lives, is represented by no less than fourteen species. As the Orthoceras had never been met with in the marine Muschelkalk, much surprise was naturally felt that seven or eight species of the genus should appear in the Hallstadt beds, assuming these last to belong to the Upper Trias. Among these species are some of large dimensions, associated with large Ammonites with foliated lobes, a form never seen before so low in the series, while the Orthoceras had never been seen so high.

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* Reaches its maximum in the Trias, but passes down to older rocks.

** Reach their maximum in the Trias, but pass up to newer rocks.

On the whole the rich marine fauna of Hallstadt and St. Cassian, now generally assigned to the lowest members of the Upper Trias or Keuper, leads us to suspect that when the strata of the Triassic age are better known, especially those belonging to the period of the Bunter Sandstone, the break between the Palæozoic and Mesozoic Periods may be almost effaced. Indeed some geologists are not yet satisfied that the true position of the St. Cassian beds (containing so great an admixture of types having at once both Mesozoic and Palæozoic affinities) is made out, and doubt whether they have yet been clearly proved to be newer than the Muschelkalk.

A rich fauna, comprising 225 species, of which about one-fourth are identical with those of St. Cassian, has been brought to light at d'Esino in Lombardy, and has been admirably illustrated by Professor Stoppani.[1] He describes 65 species of the genus of spiral univalve Chemnitzia, reminding us by its abundance of the Cerithia of the Paris basin, while the enormous size of some specimens would almost bear comparison with the *Cerithium giganteum* of that Eocene formation.

Muschelkalk.—The next member of the Trias in Germany, the *Muschelkalk*, which underlies the *Keuper* before described, consists chiefly of a compact greyish limestone, but includes beds of dolomite in many places, together with gypsum and rock salt. This limestone—a formation, perhaps, wholly unrepresented in England—abounds in fossil shells, as the name implies. Among the Cephalopoda there are no belemnites, and no ammonites with completely foliated sutures, as in the Lias and Oolite and the Hallstadt beds; but we find instead a genus allied to the Ammonite (fig. 409), called *Ceratites* by De Haan, in which the descending lobes terminate in a few small denticulations or sutures pointing inwards. Among the bivalve crustacea, the *Estheria minuta*, Bronn (see fig. 397, p. 358), is abundant, ranging through the Keuper and Muschelkalk; and

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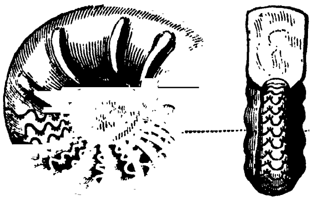
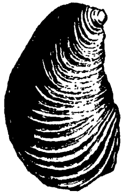
[1] Stoppani, Les Pétrifactions d'Esino. Milan, 1858—1860.

Fig. 409.



Ceratites nodosus, Schloth. Muschelkalk, Germany. Side and front view, showing the denticulated outline of the septa dividing the chambers.

Fig. 410.

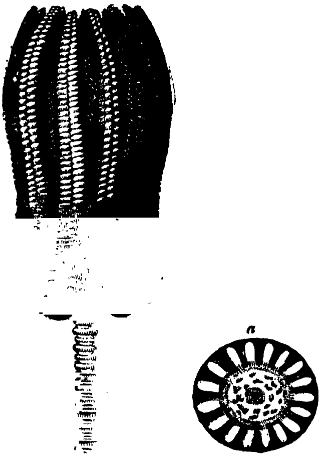


Gervillia (Avicula) socialis, Schloth. Characteristic shell of the Muschelkalk.

Gervillia socialis (fig. 410), having a similar range, is found in great numbers in the Muschelkalk of Germany, France, and Poland.

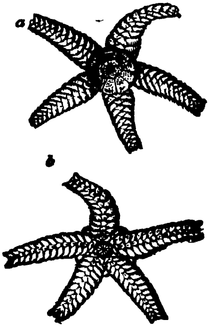
The abundance of the heads and stems of lily encrinites, *Encrinus liliiformis* (fig. 411) (or *Encrinites moniliformis*), shows

Fig. 411.



Encrinus liliiformis, Schlott. Syn. *E. moniliformis*. Body, arms, and part of stem. *a*. Section of stem. Muschelkalk.

Fig. 412.

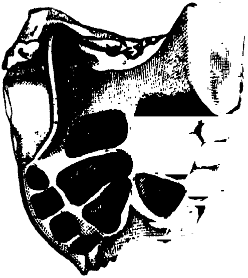


Aspidura loricata, Agass. *a*. Upper side. *b*. Lower side. Muschelkalk.

the slow manner in which some beds of this limestone have been formed in clear sea water. The star-fish called *Aspidura lori-*

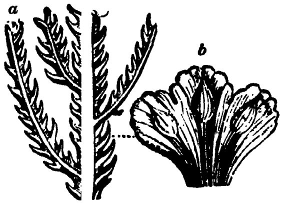
412) is as yet peculiar to the Muschelkalk. In the same formation are found the skull and teeth of a reptile of the genus *Placodus* (see fig. 413), which was referred originally by Münster, and afterwards by Agassiz, to the class of fishes. But more perfect specimens enabled Professor Owen, in 1858, to show that this fossil was a Saurian, which probably fed on shell-bearing mollusks, and used its short and flat teeth, so thickly coated with enamel, for pounding and crushing the shells.

Fig. 413.



Palatal teeth of *Placodus gigas*.
Muschelkalk.

Fig. 414.



a. *Voltzia heterophylla*. (Syn. *Voltzia brevifolia*.)
b. Portion of same magnified to show fructification. Sulzbad.
Bunter-sandstein.

Bunter-sandstein.—The *Bunter-sandstein* consists of various-coloured sandstones, dolomites, and red clays, with some beds, especially in the Hartz, of calcareous pisolite or roe-stone, the whole sometimes attaining a thickness of more than 1,000 feet. The sandstone of the Vosges is proved, by its fossils, to belong to this lowest member of the Triassic group. At Sulzbad (or Soultz-les-bains), near Strasburg, on the flanks of the Vosges, many plants have been obtained from the 'Bunter,' especially conifers of the extinct genus *Voltzia*, of which the fructification has been preserved. (See fig. 414.) Out of thirty species of ferns, cycads, conifers, and other plants, enumerated by M. Ad. Brongniart, in 1849, as coming from the 'Grès Bigarré,' or Bunter, not one is common to the Keuper.

The footprints of Labyrinthodon observed in the clays of this formation at Hildburghausen, in Saxony, have already been mentioned. Some idea of the variety and importance of the terrestrial vertebrate fauna of the three members of the Trias in Northern Germany may be derived from the fact that in the great monograph by the late Hermann von Meyer on the reptiles of the Trias, the remains of no less than eighty distinct species are described and figured.

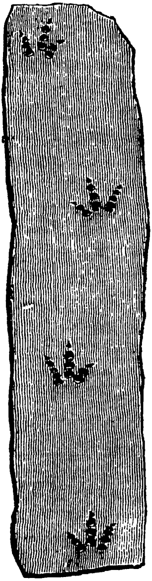
TRIAS OF THE UNITED STATES.

New Red Sandstone of the Valley of the Connecticut River.—In a depression of the granitic or hypogene rocks in the States of Massachusetts and Connecticut, strata of red sandstone, shale, and conglomerate are found, occupying an area more than 150 miles in length from north to south, and about 5 to 10 miles in breadth, the beds dipping to the eastward at angles varying from 5 to 50 degrees. The extreme inclination of 50 degrees is rare, and only observed in the neighbourhood of masses of trap which have been intruded into the red sandstone while it was forming, or before the newer parts of the deposit had been completed. Having examined this series of rocks in many places, I feel satisfied that they were formed in shallow water, and for the most part near the shore, and that some of the beds were from time to time raised above the level of the water, and laid dry, while a newer series, composed of similar sediment, was forming.

According to Professor Hitchcock, the footprints of no less than thirty-two species of bipeds, and twelve of quadrupeds, have been already detected in these rocks. Thirty of these are believed to be those of birds, four of lizards, two of chelonians, and six of batrachians. The tracks have been found in more than twenty places, scattered through an extent of nearly 80 miles from north to south, and they are repeated through a succession of beds attaining at some points a thickness of more than 1,000 feet.[1]

The bipedal impressions are for the most part trifid, and show the same number of joints as exist in the feet of living tridactylous birds. Now, such birds have three phalangeal bones for the inner toe, four for the middle, and five for the outer one (see fig. 415); but the impression of the terminal joint is that of the nail only. The fossil footprints exhibit regularly, where the joints are seen, the same number; and we see in each continuous line of tracks the three-jointed and five-jointed toes placed alternately outwards, first on the one side and then on

Fig. 415.



Footprints of a bird. Turner's Falls, Valley of the Connecticut.

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[1] Hitchcock, Mem. of Amer. Acad., New Series, vol. iii. p. 129. 1848.

the other. In some specimens, besides impressions of the three toes in front, the rudiment is seen of the fourth toe behind. It is not often that the matrix has been fine enough to retain impressions of the integument or skin of the foot; but in one fine specimen found at Turner's Falls on the Connecticut, by Dr. Deane, these markings are well preserved, and have been recognised by Professor Owen as resembling the skin of the ostrich, and not that of reptiles.

The casts of the footprints show that some of the fossil bipeds of the red sandstone of Connecticut had feet four times as large as the living ostrich, but scarcely perhaps larger than the Dinornis of New Zealand, a lost genus of feathered giants related to the Apteryx, of which there were many species which have left their bones and almost entire skeletons in the superficial alluvium of that island. By referring to what was said of the Iguanodon of the Wealden the reader will perceive that the Dinosaur was somewhat intermediate between reptiles and birds and left a series of tridactylous impressions on the sand.

To determine the exact age of the red sandstone and shale containing these ancient footprints in the United States, is not possible at present. No fossil shells have yet been found in the deposit, nor plants in a determinable state. The fossil fish are numerous and very perfect; but they are of a peculiar type, called *Ischypterus*, by Sir Philip Egerton, from the great size and strength of the fulcral rays of the dorsal fin, from ἰσχὺς, strength, and πτερὸν, a fin.

The age of the Connecticut beds cannot be proved by direct superposition, but may be presumed from the general structure of the country. That structure proves them to be newer than the movements to which the Appalachian or Alleghany chain owes its flexures, and this chain includes the ancient or palæozoic coal-formation among its contorted rocks.

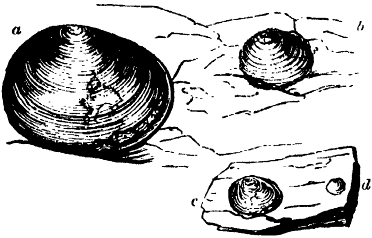
Coal-field of Richmond, Virginia.—In the State of Virginia, at the distance of about 13 miles eastward of Richmond, the capital of that State, there is a coal-field occurring in a depression of the granite rocks, and occupying a geological position analogous to that of the New Red Sandstone, above mentioned, of the Connecticut valley. It extends 26 miles from north to south, and from 4 to 12 from east to west.

The plants consist chiefly of zamites, calamites, equiseta, and ferns, and upon the whole are considered by Professor Heer to have the nearest affinity to those of the European Keuper.

The equiseta are very commonly met with in a vertical position more or less compressed perpendicularly. It is clear that they grew in the places where they are now buried in strata of hardened sand and mud. I found them maintaining their erect attitude, at points many miles apart, in beds both above and between the seams of coal. In order to explain this fact we must suppose such shales and sandstones to have been gradually accumulated during the slow and repeated subsidence of the whole region.

The fossil fish are Ganoids, some of them of the genus *Catopterus*, others belonging to the liassic genus *Tetragonolepis* (*Æchmodus*) (see fig. 383, p. 345). Two species of *Entomostraca* called *Estheria* are in such profusion in some shaly beds as to divide them like the plates of mica in micaceous shales (see fig. 416).

Fig. 416.



a. Estheria ovata. *b.* Young of same.
c. Natural size of *a*. *d.* Natural size of *b*,
Triassic coal-shale, Richmond, Virginia.

These Virginian coal-measures are composed of grits, sandstones, and shales, exactly resembling those of older or primary date in America and Europe, and they rival or even surpass the latter in the richness and thickness of the coal-seams. One of these, the main seam, is in some places from 30 to 40 feet thick, composed of pure bituminous coal. The coal is like the finest kinds shipped at Newcastle, and when analysed yields the same proportions of carbon and hydrogen—a fact worthy of notice when we consider that this fuel has been derived from an assemblage of plants very distinct specifically, and in part generically, from those which have contributed to the formation of the ancient or palæozoic coal.

Triassic mammifer.—In North Carolina, the late Professor Emmons has described the strata of the Chatham coal-field, which correspond in age to those near Richmond in Virginia. In beds underlying them he has met with three jaws of a small insectivorous mammal, which he has called *Dromatherium sylvestre*, closely allied to *Spalacotherium*. Its nearest living analogue, says Professor Owen, 'is found in Myrmecobius; for each ramus of the lower jaw contained ten small molars in a continuous series, one canine, and three conical incisors—the latter being divided by short intervals.'

Low grade of early mammals favourable to the theory of progressive development.—There is every reason to believe that this fossil quadruped is at least as ancient as the Microlestes of the European Trias above described, p. 356; and the fact is highly important, as proving that a certain low grade of marsupials had not only a wide range in time from the Trias to the Purbeck or uppermost oolitic strata of Europe, but had also a wide range in space, namely, from Europe to North America, in an east and west direction, and, in regard to latitude, from Stonesfield, in 52° N., to that of North Carolina, in 35° N.

If the three localities in Europe where the most ancient mammalia have been found—Purbeck, Stonesfield, and Stuttgardt—had belonged all of them to formations of the same age, we might well have imagined so limited an area to have been peopled exclusively with pouched quadrupeds, just as Australia now is, while other parts of the globe were inhabited by placentals; for Australia now supports one hundred and sixty species of marsupials, while the rest of the continents and islands are tenanted by about seventeen hundred species of mammalia, of which only forty-six are marsupial, namely, the opossums of North and South America. But the great difference of age of the strata in each of these three localities seems to indicate the predominance throughout a vast lapse of time (from the era of the Upper Trias to that of the Purbeck beds) of a low grade of quadrupeds; and this persistency of similar generic and ordinal types in Europe while the species were changing, and while the fish, reptiles, and mollusca were undergoing great modifications, would naturally lead us to suspect that there must also have been a vast extension in space of the same marsupial forms during that portion of the Secondary or Mesozoic epoch which has been termed 'the age of reptiles.' Such an inference as to the wide geographical range of the ancient marsupials has been confirmed by the discovery in the Trias of North America of the above-mentioned Dromatherium. The predominance in earlier ages of these mammalia of a low grade, and the absence, so far as our investigations have yet gone, of species of higher organisation, whether aquatic or terrestrial, is certainly in favour of the theory of progressive development.

PRIMARY OR PALÆOZOIC SERIES.

CHAPTER XXII.

PERMIAN OR MAGNESIAN LIMESTONE GROUP.

Line of separation between Mesozoic and Palæozoic rocks—Distinctness of Triassic and Permian fossils—Term Permian—Thickness of calcareous and sedimentary rocks in North of England—Upper—Middle—and Lower Permian—Marine shells and corals of the English Magnesian Limestone—Reptiles and fish of Permian marl slate—Footprints of reptiles—Angular breccias in Lower Permian—Extent of land in the Permian Period—Permian rocks of the Continent—Zechstein and Rothliegendes of Thuringia—Permian flora—Its generic affinity with the Carboniferous.

and variety of fossils both vertebrate and invertebrate. Professor Sedgwick in 1832[1] described what is now recognised as the central member of this group, the Magnesian Limestone, showing that it attained a thickness of 600 feet along the north-east of England, in the counties of Durham, Yorkshire, and Nottinghamshire, its lower part often passing into a fossiliferous marl-slate and resting on an inferior Red Sandstone, the equivalent of the Rothliegendes of Germany. It has since been shown that some of the Red Sandstones of newer date also belong to the Permian group; and it appears from the observations of Mr. Binney, Sir R. Murchison, Mr. Harkness, and others that it is in the region where the limestone is most largely developed, as for example in the county of Durham, that the associated red sandstones or sedimentary rocks are thinnest, whereas in the country where the latter are thickest the calcareous member is reduced to 30 or even sometimes to 10 feet. It is clear, therefore, says Mr. Hull, that the sedimentary region in the north of England area has been to the westward, and the calcareous area to the eastward; and that in this group there has been a development from opposite directions of the two types of strata.

In illustration of this he has given us the following table.

THICKNESS OF PERMIAN STRATA IN NORTH OF ENGLAND.

		NW. of England feet	NE. of England feet
Upper Permian	(Sedimentary) . .	600	50-100
Middle ,,	(Calcareous) . .	10–30	600
Lower ,,	(Sedimentary) . .	3,000	100-250[2]

Upper Permian.—What is called in this table the Upper Permian will be seen to attain its chief thickness in the north-west or on the coast of Cumberland, as at St. Bees Head, where it is described by Sir Roderick Murchison as consisting of red sandstones and red clays with gypsum resting on a thin course of Magnesian Limestone with fossils, which again is connected with the Lower Red Sandstones, resembling the upper one in such a manner that the whole forms a continuous series. No fossil footprints have been found in this Upper as in the Lower Red Sandstone.

Middle Permian—Magnesian Limestone and Marl-slate.—This formation is seen upon the coast of Durham and Yorkshire, between the Wear and the Tees. Among its characteristic fossils are *Schizodus Schlotheimi* (fig. 417) and *Mytilus septifer* (fig. 419). These shells occur at Hartlepool and Sunderland, where the rock assumes an oolitic and botryoidal character. Some of the beds in this division are ripple-marked. In some parts of the coast of Durham, where the rock is not crystalline, it contains as much as 44 per cent. of carbonate of magnesia, mixed with carbonate of lime. In other places—for it is extremely variable in structure—it consists chiefly of carbonate of lime, and has concreted into globular and hemispherical masses, varying from the size of a marble to that of a cannon-ball, and radiating from the centre. Occasionally earthy and pulverulent beds pass into compact limestone or hard granular dolomite. Sometimes the limestone appears in a brecciated form, the fragments which are united together not consisting of foreign rocks, but seemingly composed of the breaking-up of the Permian limestone itself, about the time of its consolidation.

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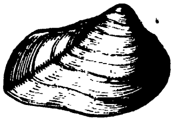
[1] Trans. Geol. Soc. Lond., Second Series, vol. iii. p. 37.

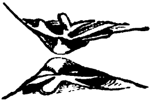
[2] Edward Hull, Ternary Classification, Quart. Journ. of Science, 1869, No. xxiii.

Fig. 417.



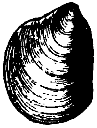
Schizodus Schlotheimi, Geinitz.
Permian crystalline
limestone.

Fig. 418.



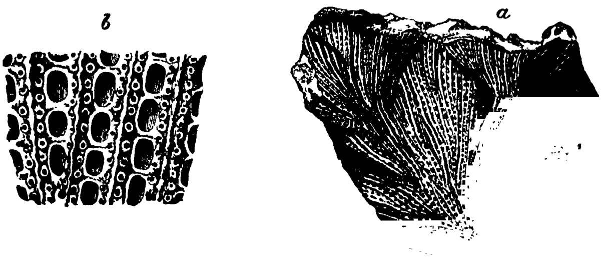
The hinge of *Schizodus*
truncatus, King.
Permian.

Fig. 419.



Mytilus septifer, King.
Syn. *Modiola acuminata*,
Sow. Permian
crystalline limestone.

Fig. 420.



a. *Fenestella retiformis*, Schlot., sp.
Syn. *Gorgonia infundibuliformis*, Goldf.; *Retepora flustracea*, Phillips.
b. Part of the same highly magnified.
Magnesian Limestone, Humbleton Hill, near Sunderland.[1]

Some of the angular masses in Tynemouth cliff are 2 feet in diameter.

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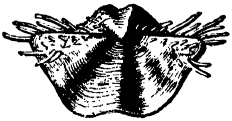
[1] King's Monograph, Pl. 2.

The magnesian limestone sometimes becomes very fossiliferous and includes in it delicate polyzoa, one of which, *Fenestella retiformis* (fig. 420), is a very variable species, and has received many different names. It sometimes attains a large size, single specimens measuring 8 inches in width. The same polyzoan, with four other British species, is also found abundantly in the Permian of Germany.

The total known fauna of the Permian series of Great Britain at present numbers 147 species, of which 77, or more than half, are mollusca. Not one of these is common to rocks newer than the Palæozoic, and the brachiopods are the only group which have furnished species common to the more ancient or Carboniferous rocks. Of these *Lingula Credneria* (fig. 422) is an example. There are 25 gasteropods and only one cephalopod, *Nautilus Freieslebeni*, which is also found in the German Zechstein.

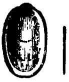
Shells of the genera *Productus* (fig. 421) and *Strophalosia* (the latter of allied form with hinge teeth), which do not occur in strata newer than the Permian, are abundant in the ordinary yellow magnesian limestone, as will be seen in the valuable memoirs of Messrs. King and Howse. They are accompanied by certain species of *Spirifera* (fig. 423), *Lingula Credneria* (fig. 422), and other brachiopoda characteristic of the primary or palæozoic formations. Some of this same tribe of shells, such as *Camarophoria* allied to *Rhynchonella*, *Spiriferina*, and two species of *Lingula*, are specifically the same as fossils of the Carboniferous rocks. *Avicula*, *Arca*, and *Schizodus* (fig. 417), and other lamellibranchiate bivalves, are abundant, but spiral univalves are very rare.

Fig. 421.



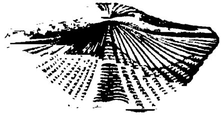
Productus horridus, Sowerby.
(*P. Calvus*, Sow.)
Sunderland and Durham, in Magnesian Limestone; Zechstein and Kupferschiefer, Germany.

Fig. 422.



Lingula Credneria.
(Geinitz.)
Magnesian Limestone, and Carboniferous.
Marl-slate, Durham; Zechstein, Thuringia.

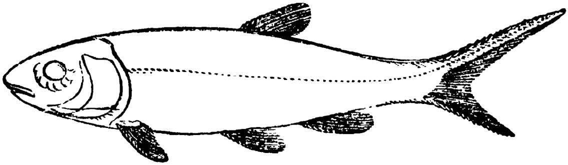
Fig. 423.



Spirifera alata, Schloth.
Syn. *Trigonotreta undulata*, Sow, King's Monogr.
Magnesian Limestone.

Beneath the limestone lies a formation termed the marl-slate, which consists of hard, calcareous shales, marl-slate and thin-bedded limestones. At East Thickley, in Durham, where it is thirty feet thick, this slate has yielded many fine specimens of fossil fish—of the genera *Palæoniscus* 10 species, *Pygopterus* 2 species, *Cœlacanthus* 2 species, and *Platysomus* 2 species, which as genera are common to the older Carboniferous formation; but the Permian species are peculiar, and, for the most part, identical with those found in the marl-slate or copper-slate of Thuringia.

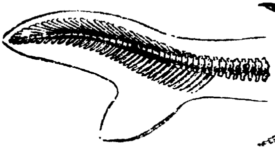
Fig. 424.



Restored outline of a fish of the genus *Palæoniscus*, Agass.
Palæothrissum, Blainville.

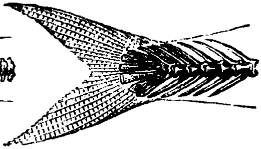
The *Palæoniscus* above mentioned belongs to that division of fishes which M. Agassiz has called ‘Heterocercal,’ which have their tails unequally bilobate, like the recent shark and sturgeon, and the vertebral column running along the upper caudal lobe. (See fig. 425.) The ‘Homocercal’ fish, which comprise almost all the 9,000 species at present known living, have the tail-fin either single or equally divided; and the vertebral column stops short, and is not prolonged into either lobe. (See fig. 426.) Now it is a singular fact, first pointed out by Agassiz, that the heterocercal form, which is confined to a small number of existing genera, is universal in the magnesian limestone, and all the more ancient formations. It characterises the earlier periods of the earth's history, whereas in the secondary strata, or those newer than the Permian, the homocercal tail greatly predominates.

Fig. 425.



Shark.
Heterocercal.

Fig. 426.



Shad. (*Clupea*. Herring tribe.)
Homocercal.

In Prof. King's monograph before referred to, a full description has been given by Sir Philip Egerton of the species of fish characteristic of the marl-slate; and figures of the ichthyolites, which are very entire and well preserved, will be found in the same memoir. Even a single scale is usually so characteristically marked as to indicate the genus, and sometimes even the particular species. They are often scattered through the beds singly, and may be useful to a geologist in determining the age of the rock.

SCALES OF FISH. MAGNESIAN LIMESTONE.

Fig. 427.

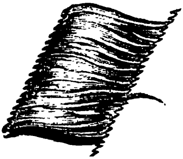


Fig. 428.

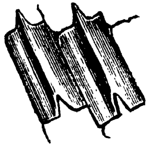


Fig. 429.

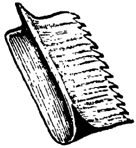


Fig. 430.

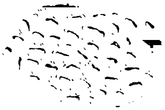
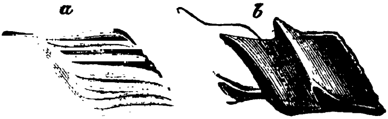


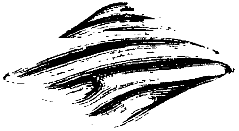
Fig. 427. *Palæoniscus comptus*, Agassiz, Scale, magnified. Marl-slate.
Fig. 428. *Palæoniscus elegans*, Sedg. Under surface of scale, magnified. Marl-slate.
Fig. 429. *Palæoniscus glaphyrus*, Ag. Under surface of scale, magnified. Marl-slate.
Fig. 430. *Cœlacanthus granulatus*, Ag. Granulated surface of scale, magnified. Marl-slate.

Fig. 431.



Pygopterus mandibularis, Ag. Marl-slate.
a. Outside of scale, magnified.
b. Under surface of same.

Fig. 432.



Acrolepis Sedgwickii, Ag.
Outside of scale, magnified.
Marl-slate.

We are indebted to Mr. Joseph Duff, of Bishop's Auckland, as mentioned by Messrs. Hancock and Howse, for the discovery in this marl-slate at Midderidge, Durham, of two species of *Protorosaurus*, a genus of reptiles, one representative of which, *P. Speneri*, has been celebrated ever since the year 1810 as characteristic of the Kupfer-schiefer or Permian of Thuringia. Professor Huxley informs us that the agreement of one of the Durham fossils with Hermann von Meyer's figure of the German specimen is most striking. Although the head is wanting in all the examples yet found, they clearly belong to the Lacertian order, and are therefore of a higher grade than any other vertebrate animal hitherto found fossil in a Palæozoic rock. Remains of a Labyrinthodont, *Lepidotosaurus Duffii*,[1] have been met with in the same slate near Durham; and a quarry in the Permian sandstone of Kenilworth has yielded the skull of another species called by Professor Huxley *L. Dasyceps*, on account of the roughness of the surface of the cranium.

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[1] Hancock and Howse, Quart. Geol. Journ., vol. xxvi. pl. xxxviii.

Lower Permian.—The beds which lie beneath the marl-slate consist of sandstone and sand, separating the Magnesian Limestone from the coal, in Yorkshire and Durham. In some instances, red marl and gypsum have been found associated with these beds. They have been classed with the Magnesian Limestone by Professor Sedgwick, as being nearly co-extensive with it in geographical range, though their relations are very obscure. But the principal development of Lower Permian is, as we have seen by Mr. Hull's table (p. 376) in the north-west, where the Penrith sandstone, as it has been called, and the associated breccias and purple shales are estimated by Professor Harkness to attain a thickness of 3,000 feet. Organic remains are generally wanting, foot-prints and worm-tracks are occasionally met with, and the leaves, cones, and wood of coniferous plants have been found in beds considered by Professor Harkness to be the equivalent of the marl-slate which overlies the Penrith sands at Hilton. Also in the red sandstones of Corncockle Muir near Dumfries very distinct footprints of reptiles occur, originally referred to the Trias, but shown by Mr. Binney in 1856 to be Permian. No bones of the animals which they represent have yet been discovered.

Angular breccias in Lower Permian.—A striking feature in these beds is the occasional occurrence, especially at the base of the formation, of angular and sometimes rounded fragments of Carboniferous and older rocks of the adjoining districts being included in a red matrix. Some of the angular masses are of huge size.

In the central and southern counties, where the Middle Permian or Magnesian Limestone is wanting, it is difficult to separate the upper and lower sandstones, and Mr. Hull is of opinion that the patches of this formation found here and there in Worcestershire, Shropshire, and other counties may have been deposited in a sea separated from the northern basin by a barrier of Carboniferous rocks running east and west, and now concealed under the Triassic strata of Cheshire. Similar breccias to those before described are found in the more southern counties last mentioned, where their appearance is rendered more striking by the marked contrast they present to the beds of well-rolled and rounded pebbles of the Trias occupying a large area in the same region.

Professor Ramsay refers the angular form and large size of the fragments composing these breccias to the action of floating ice in the sea. These masses of angular rock, some of them weighing more than half a ton, and lying confusedly in a red unstratified marl, like stones in boulder-drift, are in some cases polished, striated, and furrowed like erratic blocks in the moraine of a glacier. They can be shown in some cases to have travelled from the parent rocks, thirty or more miles distant, and yet not to have lost their angular shape.[1]

Extent of land in the Permian Period.—I have already mentioned, when treating of the Keuper, that Professor Ramsay considers the Triassic strata to have been formed in inland lakes during a Continental period, and he is disposed to believe that similar conditions prevailed during the deposition of the Permian series. The footprints of the vale of Eden, he remarks, the sun-cracks, rain-pittings, and ripplings impressed upon the beds, apparently indicate shore-surfaces, and the dwarfed and poverty-stricken nature of the magnesian limestone fossils of the Upper Permian strata of Lancashire resembles the living molluscan fauna of the Caspian Sea. On the other hand, the Magnesian Limestone of the east of England contains a much richer marine fauna, affording indications of a freer communication with the ocean.[2]

Permian rocks of the Continent.—Germany is the classic ground of the Magnesian Limestone now called Permian. The formation was well studied by the miners of that country a century ago, being known to contain a thin band of dark-coloured cupriferous shale, characterised at Mansfeld in Thuringia by numerous fossil fish. Beneath some variegated sandstones (not belonging to the Trias, though often confounded with it) they came down first upon a dolomitic limestone corresponding to the upper part of our Middle Permian, and then upon a marl-slate richly impregnated with copper pyrites, and containing fish and reptiles (Protorosaurus) identical in species with those of the corresponding marl-slate of Durham. To the limestone they gave the name of Zechstein, and to the marl-slate that of Mergel-schiefer or Kupfer-schiefer. Beneath the fossiliferous group lies the Rothliegendes or Roth-todt-liegendes, meaning the red-lyer or red-dead-lyer, the first name being given to it by the German miners from its colour, and the second because the copper had *died out* when they reached this underlying non-metalliferous member of the series. This red under-lyer is, in fact, a great deposit of red sandstone, breccia, and conglomerate with associated porphyry, basalt, and amygdaloid.

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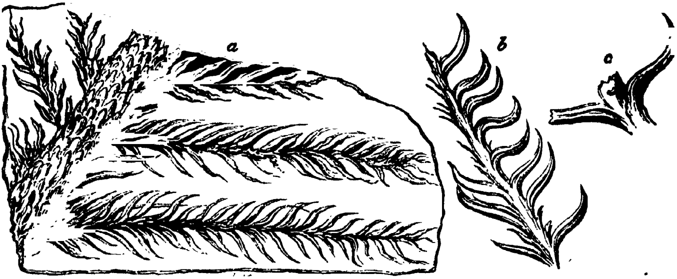
[1] Ramsay, Quart. Geol. Journ. 1855, and Lyell, Principles of Geology, vol. i. p. 223, 10th edit.

[2] Ramsay, Quart. Geol. Journ. vol. xxvii. p. 247.

In Russia, according to Sir R. Murchison, the Permian rocks are composed of white limestone, with gypsum and white salt; and of red and green grits, occasionally with copper ore; also magnesian limestones, marlstones, and conglomerates.

Permian flora.—About 18 or 20 species of plants are known in the Permian rocks of England. None of them pass down into the Carboniferous series, but several genera, such as *Alethopteris*, *Neuropteris*, and *Walchia*, are common to the two groups. The Permian flora on the Continent appears, from the researches of MM. Murchison and de Verneuil in Russia, and of MM. Geinitz and von Gutbier in Saxony, to be, with few exceptions, distinct from that of the coal.

Fig. 433.

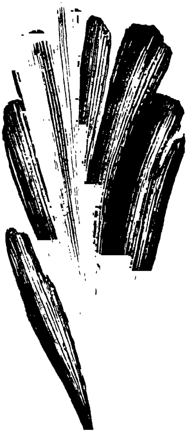


Walchia piniformis, Schloth. Permian, Saxony. (Gutbier, Die Versteinerungen des Permischen Systemes in Sachsen, vol. ii. pl. x.)

a. Branch. *b.* Twig of the same. *c.* Leaf magnified.

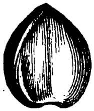
In the Permian rocks of Saxony no less than 60 species of fossil plants have been met with. Two or three of these, as *Calamites gigas*, *Sphenopteris erosa*, and *S. lobata*, are also met with in the government of Perm in Russia. Seven others, and among them *Neuropteris Loshii*, *Pecopteris arborescens*, and *P. similis*, and several species of *Walchia* (see fig. 433), a genus of Conifers called

Fig. 435.



Noeggerathia cuneifolia. Brongniart.[1]

Fig. 434.



Cardiocarpon Ottonis. Gutbier.

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[1] Murchison's Russia, vol. ii. pl. A. fig. 3.

Lycopodites by some authors, are said by Geinitz to be common to the coal-measures.

Among the genera also enumerated by Colonel Gutbier are the fruit called *Cardiocarpon* (see fig. 434), *Asterophyllites*, and *Annularia*, so characteristic of the Carboniferous period; also *Lepidodendron*, which is common to the Permian of Saxony, Thuringia, and Russia, although not abundant. *Noeggerathia* (see fig. 435), the leaves of which have parallel veins without a mid-rib, and to which various generic synonyms, such as *Cordaites*, *Flabellaria*, and *Poacites*, have been given, is another link between the Permian and Carboniferous vegetation. Coniferæ, of the Araucarian division, also occur; but these are likewise met with both in older and newer rocks. The plants called *Sigillaria* and *Stigmaria*, so marked a feature in the Carboniferous period, are as yet wanting in the true Permian.

Among the remarkable fossils of the Rothliegendes, or lowest part of the Permian in Saxony and Bohemia, are the silicified trunks of tree-ferns called generically *Psaronius*. Their bark was surrounded by a dense mass of air-roots, which often constituted a great addition to the original stem, so as to double or quadruple its diameter. The same remark holds good in regard to certain living extra-tropical arborescent ferns, particularly those of New Zealand.

Thus we see that while upon the whole the plants of the marl-slate or Middle Permian differ considerably from those of the Coal Period, the plants of the Rothliegende of Germany which belong to the Lower Permian begin to show a very close generic affinity with Carboniferous forms.

CHAPTER XXIII.

THE COAL OR CARBONIFEROUS GROUP.

Principal subdivisions of the Carboniferous Group—Different thickness of the sedimentary and calcareous members in Scotland and the South of England—Coal-measures—Terrestrial nature of the growth of coal—Erect fossil trees—Uniting of many coal-seams into one thick bed—Purity of the coal explained—Conversion of coal into anthracite—Origin of clay iron-stone—Marine and brackish-water strata in coal—Fossil insects—Batrachian reptiles—Carboniferous Amphibia—Labyrinthodont foot-prints in coal-measures—Nova Scotia coal-measures with successive growths of erect fossil trees—Structure of American and European coal—Air-breathers of the American coal—Changes of condition of land and sea indicated by the Carboniferous strata of Nova Scotia.

Principal subdivisions of the Carboniferous Group.—The next group which we meet with in descending order is the Carboniferous, commonly called 'The Coal;' because it contains many beds of that mineral, in a more or less pure state, interstratified with sandstones, shales, and limestones. The coal itself, even in Great Britain and Belgium, where it is most abundant, constitutes but an insignificant portion of the whole mass. In South Wales, for example, the thickness of the coal-bearing strata has been estimated at between 11,000 and 12,000 feet, while the various coal-seams, about 80 in number, do not, according to Prof. Phillips, exceed in the aggregate 120 feet.

The carboniferous formation assumes various characters in different parts even of the British Islands. It usually comprises two very distinct members: 1st, the sedimentary beds, usually called the Coal-measures, of mixed freshwater, terrestrial, and marine origin, including seams of coal; 2ndly, that named in England the Mountain or Carboniferous Limestone, of purely marine origin, and made up chiefly of corals, shells, and encrinites, and resting on alternating beds of limestone and shale called the Lower Limestone shale.

In the south-western part of our island, in Somersetshire and South Wales, the three divisions usually spoken of are:—

1. Coal-measures	Strata of shale, sandstone, and grit, from 600 to 10,000 feet thick, with occasional seams of coal.
2. Mill-stone grit	A coarse quartzose sandstone and conglomerate, sometimes used for millstones, with beds of shale; usually devoid of coal; occasionally above 600 feet thick; commonly called 'Farewell Rock.'
3. Mountain or Carboniferous Limestone.	A calcareous rock containing marine shells, corals, and encrinites; thickness variable, sometimes more than 2,000 feet.

If the reader will refer to the section fig. 85, p. 107, he will see that the Upper and Lower Coal-measures of the Coal-field near Bristol are divided by a micaceous flaggy sandstone called the Pennant Rock, about 1,500 feet thick. The Lower Coal-measures of the same section rest on a base of coarse grit called the Millstone Grit (No. 2 of the above table).

In the South Welsh coal-field Millstone Grit occurs in like manner at the base of the productive coal-measures. It is called by the miners the 'Farewell Rock,' as when they reach it they have no longer any hopes of obtaining coal at a greater depth in the same district. In the central and northern coal-fields of England this same Grit, including quartz pebbles, with some accompanying sandstones and shales containing coal plants, acquires a thickness of several thousand feet, lying beneath the productive coal-measures, which are nearly 10,000 feet thick.

Below the Millstone Grit is a continuation of similar sandstones and shales called by Professor Phillips the Yoredale series, from Yoredale, in Yorkshire, where they attain a thickness of from 800 to 1,000 feet. At several intervals bands of limestone divide this part of the series, one of which, called the Main Limestone or Upper Scar Limestone, composed in great part of encrinites, is 70 feet thick. Thin seams of coal also occur in these lower Yoredale beds in Yorkshire, showing that in the same region there were great alternations in the state of the surface. For at successive periods in the same area there prevailed first, terrestrial conditions favourable to the formation of pure coal, secondly, a sea of some depth suited to the formation of Carboniferous Limestone, and, thirdly, a supply of muddy sediment and sand, furnishing the materials for sandstone and shale. There is no clear line of demarcation between the Coal-measures and the Millstone Grit, nor between the Millstone Grit and underlying Yoredale rocks.

On comparing a series of vertical sections in a north-westerly direction from Leicestershire and Warwickshire into North Lancashire we find, says Mr. Hull, within a distance of 120 miles an augmentation of the sedimentary materials to the extent of 16,000 feet.

	Feet
Leicestershire and Warwickshire	2,600
North Staffordshire	9,000
South Lancashire	12,130
North Lancashire	18,700

In central England, where the sedimentary beds are reduced to about 3,000 feet in all, the Carboniferous Limestone attains an enormous thickness, according to Mr. Hull's estimate, as much as 4,000 feet at Ashbourne, near Derby. To a certain extent, therefore, we may consider the calcareous member of the formation as having originated simultaneously with the accumulation of the materials of grit, sandstone, and shale, with seams of coal; just as strata composed of mud, sand, and pebbles, several thousand feet thick, with layers of vegetable matter, are now in the process of formation in the cypress swamps and delta of the Mississippi, while coral reefs are simultaneously forming on the coast of Florida, and in the sea of the Bermuda islands. For we may safely conclude that in the ancient Carboniferous ocean those marine animals which secreted lime were never freely developed in areas where the rivers poured in freshwater charged with sand or clay; and the limestone could only become several thousand feet thick over parts of the ocean bed, which was being slowly depressed, the water remaining perfectly clear for ages.

The calcareous strata of the Scotch coal-fields, those of Lanarkshire, the Lothians, and Fife for example, are very insignificant in thickness when compared to those of England. They consist of a few beds intercalated between the sandstones and shales containing coal and ironstone, the combined thickness of all the limestones amounting to no more than 150 feet. The vegetation of some of these northern sedimentary beds containing coal may be older than any of the coal-measures of central and southern England as being coeval with the Mountain Limestone of the south. In Ireland the limestone predominates over the coal-bearing sands and shales. We may infer the former continuity of several of the coal-fields in northern and central England, not only from the abrupt manner in which they are cut off at their outcrop, but from their remarkable correspondence in the succession and character of particular beds. But the limited extent to which these strata are exposed at the surface is not merely owing to their former denudation, but even in a still greater degree to their having been largely covered by the New Red Sandstone, as in Cheshire and the midland counties, and here and there by the Permian strata, as in Durham.

It has long been the opinion of the most eminent geologists that the coal-fields of Yorkshire and Lancashire were once united, the overlying upper Coal-measures, Millstone Grit, and Yoredale rocks having been subsequently removed ; but what is remarkable is the ancient date now assigned to this denudation, for it seems that a thickness of no less than 10,000 feet of the coal-measures had been carried away before the deposition even of the lower Permian rocks which were thrown down upon the already disturbed truncated edges of the coal-strata.[1] The carboniferous strata most productive of workable coal have so often a basin-shaped arrangement that these troughs have sometimes been supposed to be connected with the original conformation of the surface upon which the beds were deposited. But this structure is really owing to movements of upheaval and subsidence in the earth's crust, and the flexure and inclination of the beds has no connection with the original geographical configuration of the district.

COAL-MEASURES.

I shall now treat more particularly of the productive coal-measures and their mode of origin and organic remains.

Coal formed on land.—In South Wales, already alluded to, where the coal-measures attain a thickness of 10,000 feet, the sandstones and shales throughout appear to have been formed in water of moderate depth, during a slow, but perhaps intermittent, depression of the surface, in a region to which rivers were bringing a never-failing supply of muddy sediment and sand. The same area was alternately covered with vast forests, such as we see in the deltas of great rivers in warm climates, which are liable to be submerged beneath fresh or salt water should the land sink vertically a few feet.

In one section near Swansea, in South Wales, where the total thickness of the coal-measures is 3,246 feet, we learn from Sir H. De la Beche that there are ten principal masses of sandstone. One of these is 500 feet thick, and the whole of them make together a thickness of 2,125 feet. They are separated by masses of shale, varying in thickness from 10 to 50 feet. The intercalated coal-beds, sixteen in number, are generally from 1 to 5 feet thick, one of them, which has two or three layers of clay interposed, attaining 9 feet. At other points in the same coal-field the shales predominate over the sandstones. Great as is the diversity in the horizontal extent of individual coal-seams they all present one characteristic feature, in having, each of them, what is called its *underclay*. These underclays, co-extensive with every layer of coal, consist of arenaceous shale, sometimes called fire-clay, because it can be made into bricks which stand a furnace heat. They vary in thickness from 6 inches to more than 10 feet; and Sir William Logan first announced in 1841 that they were regarded by the colliers in South Wales as an essential accompaniment of each of the eighty or more seams of coal met with in their coal-field. They are said to form the *floor* on which the coal rests; and some of them have a slight admixture of carbonaceous matter, while others are quite blackened by it.

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[1] Edward Hull, Quart. Geol. Journ., vol. xxiv. p. 327.

All of them, as Sir William Logan pointed out, are characterised by enclosing a peculiar species of fossil plant called *Stigmaria*, to the exclusion of other plants. It was also observed that, while in the overlying shales or 'roof' of the coal, ferns and trunks of trees abound without any *Stigmariæ*, and are flattened and compressed, those singular plants of the underclay most commonly retain their natural forms, unflattened and branching freely, sending out their slender rootlets, formerly thought to be leaves, through the mud in all directions. Several species of *Stigmaria* had long been known to botanists, and described by them, before their position under each seam of coal was pointed out, and before their true nature as the roots of trees (some having been actually found attached to the base of *Sigillaria* stumps) was recognised. It was conjectured that they might be aquatic, perhaps floating plants, which sometimes extended their branches and leaves freely in fluid mud, in which they were finally enveloped.

Now that all agree that these underclays are ancient soils, it follows that in every instance where we find them they attest the terrestrial nature of the plants which formed the overlying coal, which consists of the trunks, branches, and leaves of the same plants. The trunks have generally fallen prostrate in the coal, but some of them still remain at right angles to the ancient soils (see fig. 447, p. 402). Professor Göppert, after examining the fossil plants of the coal-fields of Germany, has detected, in beds of pure coal, remains of every family hitherto known to occur fossil in the carboniferous rocks. Many seams, he remarks, are rich in *Sigillariæ*, *Lepidodendra*, and *Stigmariæ*, the latter in such abundance as to appear to form the bulk of the coal. In some places, almost all the plants were calamites, in others ferns.[1]

Between the years 1837 and 1840, six fossil trees were discovered in the coal-field of Lancashire, where it is intersected by the Bolton Railway. They were all at right angles to the plane of the bed which dips about 15° to the south. The distance between the first and the last was more than 100 feet, and the roots of all were embedded in a soft argillaceous shale. In the same plane with the roots is a bed of coal, eight or ten inches thick, which has been found to extend across the railway, or to the distance of at least ten yards. Just above the covering of the roots, yet beneath the coal-seam, so large a quantity of the *Lepidostrobus variabilis* was discovered enclosed in nodules of hard clay, that more than a bushel was collected from the small openings around the base of some of the trees (see figure of this genus, p. 417). The exterior trunk of each was marked by a coating of friable coal, varying from one quarter to three-quarters of an inch in thickness; but it crumbled away on removing the matrix. The dimensions of one of the trees is 15½ feet in circumference at the base, 7½ feet at the top, its height being 11 feet. All the trees have large spreading roots, solid and strong, sometimes branching, and traced to a distance of several feet, and presumed to extend much farther.

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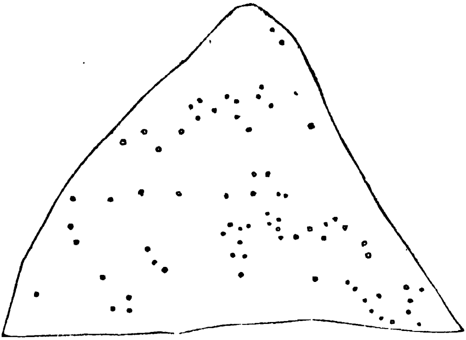
[1] Quart. Geol. Journ., vol. v., Mem., p. 17.

In a colliery near Newcastle a great number of *Sigillariæ* occur in the rock as if they had retained the position in which they grew. Not less than thirty, some of them 4 or 5 feet in diameter, were visible within an area of 50 yards square, the interior being sandstone, and the bark having been converted into coal. Such vertical stems are familiar to our coal miners, under the name of 'coal-pipes' and 'bell-moulds.' They are much dreaded, for almost every year in the Bristol, Newcastle, and other coal-fields, they are the cause of fatal accidents. Each cylindrical cast of a tree, formed of solid sandstone, and increasing gradually in size towards the base, and being without branches, has its whole weight thrown downwards, and receives no support from the coating of friable coal which has replaced the bark. As soon, therefore, as the cohesion of this external layer is overcome, the heavy column falls suddenly in a perpendicular or oblique direction from the roof of the gallery whence coal has been extracted, wounding or killing the workman who stands below. It is strange to reflect how many thousands of these trees fell originally in their native forests in obedience to the law of gravity; and how the few which continued to stand erect, obeying, after myriads of ages, the same force, are cast down to immolate their human victims.

It has been remarked, that if, instead of working in the dark, the miner was accustomed to remove the upper covering of rock from each seam of coal, and to expose to the day the soils on which ancient forests grew, the evidence of their former growth would be obvious. Thus in South Staffordshire a seam of coal was laid bare in the year 1844, in what is called an open work at Parkfield Colliery, near Wolverhampton. In the space of about a quarter of an acre the stumps of no less than seventy-three trees with their roots attached appeared, as shown in the annexed plan (fig. 436), some of them more than 8 feet in circumference. The trunks, broken off close to the root, were lying prostrate in every direction, often crossing each other. One of them measured 15, another 30 feet in length, and others less. They were invariably flattened to the thickness of one or two inches, and converted into coal. Their roots formed part of a stratum of coal 10 inches thick, which rested on a layer of clay 2 inches thick, below which was a second forest, resting on a 2-foot seam of coal. Five feet below this again was a third forest with large stumps of *Lepidodendra*, *Calamites*, and other trees.

Fig. 436.



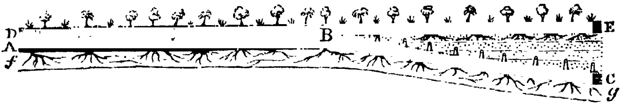
Ground plan of a fossil forest, Parkfield Colliery, near Wolverhampton, showing the position of 73 trees in a quarter of an acre.

Blending of coal-seams.—Both in England and North America seams of coal are occasionally observed to be parted from each other by layers of clay, sand, and shale, and after they have been persistent for miles to come together and blend in one single bed, which is then found to be equal in the aggregate to the thickness of the several seams. I was shown by Mr. H. D. Rogers a remarkable example of this in Pennsylvania. In the Shark Mountain, near Pottsville, in that State, there are thirteen seams of anthracite coal, some of them more than six fe thick, separated by beds of white quartzose grit and a co merate of quartz pebbles, often of the size of a her

Between Pottsville and the Lehigh Summit Mine, seven of these seams of coal, at first widely separated, are, in the course of several miles, brought nearer and nearer together by the gradual thinning out of the intervening coarse-grained strata and their accompanying shales, until at length they successively unite and form one mass of coal between forty and fifty feet thick, very pure on the whole, though with a few thin partings of clay. This mass of coal I saw quarried in the open air at Mauch Chunk, or the Bear Mountain. The origin of such a vast thickness of vegetable remains so unmixed on the whole with earthy ingredients, can be accounted for in no other way than by the growth, during thousands of years, of trees and ferns, in the manner of peat—a theory which the presence of the Stigmaria *in situ* under each of the seven layers of anthracite fully bears out. The rival hypothesis, of the drifting of plants into a sea or estuary, leaves the non-intermixture of sediment, or of clay, sand, and pebbles with the pure coal, wholly unexplained.

The late Mr. Bowman was the first who gave a satisfactory explanation of the manner in which distinct coal-seams, after maintaining their independence for miles, may at length unite, and then persist throughout another wide area with a thickness equal to that which the separate seams had previously maintained.

Fig. 437.



Uniting of distinct coal-seams.

Let A C be a 3-foot seam of coal originally laid down as a mass of vegetable matter on the level area of an extensive swamp, having an underclay *f g* through which the Stigmariæ or roots of the trees penetrate as usual. One portion B C of this seam of coal is now inclined; the area of the swamp having subsided as much as 25 feet at E C, and become for a time submerged under salt, fresh, or brackish water. Some of the trees of the original forest A B C fell down others continued to stand erect in the new lagoon, their stumps and part of their trunks becoming gradually enveloped in layers of sand and mud, which at length filled up the new piece of water C E.

When this lagoon has been entirely silted up and converted into land, the forest-covered surface A B will extend once more over the whole area A B E, and a second mass of vegetable matter

D E forming three feet more of coal will accumulate. We then find in the region E C two seams of coal, each three feet thick with their respective underclays, with erect buried trees based upon the surface of the lower coal, the two seams being separated by 25 feet of intervening shale and sandstone. Whereas in the region A B where the growth of the forest has never been interrupted by submergence, there will simply be one seam two yards thick corresponding to the united thickness of the beds B E and B C. It may be objected that the uninterrupted growth of plants during the interval of time required for the filling up of the lagoon will have caused the vegetable matter in the region D A B to be thicker than the two distinct seams E and C, and no doubt there would actually be a slight excess representing one or more generation of trees and plants forming the undergrowth; but this excess of vegetable matter when compressed into coal would be so insignificant in thickness that the miner might still affirm that the seam D A throughout the area D A B was equal to the two seams C and E.

Cause of the purity of coal.—The purity of the coal itself, or the absence in it of earthy particles and sand, throughout areas of vast extent, is a fact which appears very difficult to explain when we attribute each coal-seam to a vegetation growing in swamps. It has been asked how, during river inundations capable of sweeping away the leaves of ferns and the stems and roots of *Sigillariæ* and other trees, could the waters fail to transport some fine mud into the swamps? One generation after another of tall trees grew with their roots in mud and their leaves and prostrate trunks formed layers of vegetable matter, which was afterwards covered with mud since turned to shale. Yet the coal itself, or altered vegetable matter, remained all the while unsoiled by earthy particles. This enigma, however perplexing at first sight, may, I think, be solved by attending to what is now taking place in deltas. The dense growth of reeds and herbage which encompasses the margins of forest-covered swamps in the valley and delta of the Mississippi is such that the fluviatile waters, in passing through them, are filtered and made to clear themselves entirely before they reach the areas in which vegetable matter may accumulate for centuries, forming coal if the climate be favourable. There is no possibility of the least intermixture of earthy matter in such cases. Thus in the large submerged tract called the 'Sunk Country,' near New Madrid, forming part of the western side of the valley of the Mississippi, erect trees have been standing ever since the year 1811-12, killed by the great earthquake of that date; lacustrine and swamp plants have been there in the shallows, and several rivers have annually inundated the whole space, and yet have been unable to carry in any sediment within the outer boundaries of the morass, so dense is the marginal belt of reeds and brushwood. It may be affirmed that generally in the 'cypress swamps' of the Mississippi no sediment mingles with the vegetable matter accumulated there from the decay of trees and semi-aquatic plants. As a singular proof of this fact, I may mention that whenever any part of a swamp in Louisiana is dried up, during an unusually hot season, and the wood set on fire, pits are burnt into the ground many feet deep, or as far down as the fire can descend, without meeting with water, and it is then found that scarcely any residuum or earthy matter is left. At the bottom of all these 'cypress swamps' a bed of clay is found, with roots of the tall cyprus (*Taxodium distichum*), just as the underclays of the coal are filled with *Stigmaria*.

Conversion of bituminous coal into anthracite.—It appears from the researches of Liebig and other eminent chemists, that when wood and vegetable matter are buried in the earth exposed to moisture, and partially or entirely excluded from the air, they decompose slowly and evolve carbonic acid gas, thus parting with a portion of their original oxygen. By this means, they become gradually converted into lignite or wood-coal, which contains a larger proportion of hydrogen than wood does. A continuance of decomposition changes this lignite into common or bituminous coal, chiefly by the discharge of carburetted hydrogen, or the gas by which we illuminate our streets and houses. According to Bischoff, the inflammable gases which are always escaping from mineral coal, and are so often the cause of fatal accidents in mines, always contain carbonic acid, carburetted hydrogen, nitrogen, and olefiant gas. The disengagement of all these gradually transforms ordinary or bituminous coal into anthracite, to which the various names of glance-coal, coke, hard-coal, culm, and many others, have been given.

There is an intimate connection between the extent to which the coal has in different regions parted with its gaseous contents, and the amount of disturbance which the strata have undergone. The coincidence of these phenomena may be attributed partly to the greater facility afforded for the escape of volatile matter, when the fracturing of the rocks has produced an infinite number of cracks and crevices. The gases and water which are made to penetrate these cracks are probably rendered the more effective as metamorphic agents by increased temperature derived from the interior. It is well known that, at the present period, thermal waters and hot vapours burst out from the earth during earthquakes, and these would not fail to promote the disengagement of volatile matter from the carboniferous rocks.

In Pennsylvania the strata of coal are horizontal to the westward of the Alleghany Mountains, where the late Professor H. D. Rogers pointed out that they were most bituminous; but as we travel south-eastward, where they no longer remain level and unbroken, the same seams become progressively debitumenised in proportion as the rocks become more bent and distorted. At first on the Ohio river the proportion of hydrogen, oxygen, and other volatile matters ranges from forty to fifty per cent. Eastward of this line, on the Monongahela, it still approaches forty per cent., where the strata begin to experience some gentle flexures. On entering the Alleghany Mountains, where the distinct anticlinal axes begin to show themselves, but before the dislocations are considerable, the volatile matter is generally in the proportion of eighteen or twenty per cent. At length, when we arrive at some insulated coal-fields associated with the boldest flexures of the Appalachian chain, where the strata have been actually turned over, as near Pottsville, we find the coal to contain only from six per cent. of volatile matter, thus becoming a genuine anthracite.

Clay-ironstone.—Bands and nodules of clay-ironstone are common in the coal-measures, and are formed, says Sir H. De la Beche, of carbonate of iron mingled mechanically with earthy matter, like that constituting the shales. Mr. Robert Hunt, of the Museum of Practical Geology, instituted a series of experiments to illustrate the production of this substance, and found that decomposing vegetable matter, such as would be distributed through all coal strata, prevented the farther oxidation of the proto-salts of iron, and converted the peroxide into protoxide by taking a portion of its oxygen to form carbonic acid. Such carbonic acid, meeting with the protoxide of iron in solution, would unite with it and form a carbonate of iron; and this mingling with fine mud, when the excess of carbonic acid was removed, might form beds or nodules of argillaceous ironstone.[1]

Intercalated marine beds in coal-measures.—In the coal-fields both of Europe and America the association of fresh, brackish-water, and marine strata with coal-seams of terrestrial origin is frequently recognised. Thus, for example, a deposit near Shrewsbury, probably formed in brackish water, has been described by Sir R. Murchison as the youngest member of the coal-measures of that district, at the point where they are in contact with the overlying Permian group. It consists of shales and sandstones about 150 feet thick, with coal and traces of plants; including a bed of limestone varying from 2 to 9 feet in thickness, which is cellular, and resembles some lacustrine limestones of France and Germany. It has been traced for 30 miles in a straight line, and can be recognised at still more distant points. The characteristic fossils are a small bivalve, having the form of a *Cyclas* or *Cyrena*, also a small entomostracan, *Leperditia inflata* (fig. 439), and the small shell of a minute tubercular annelid of an extinct genus called *Microconchus* (fig. 438) allied to *Spirorbis*. In many coal-fields there are freshwater strata, some of which contain shells termed *Anthracosia*, and *Anthracomya* and referred to the family *Unionidæ*; but in the midst of the coal series in Yorkshire there is one thin but very widely spread stratum, abounding in fishes and marine shells, such as *Goniatites Listeri* (fig. 440) *Orthoceras*, and *Aviculopecten papyraceus*, Goldf. (fig. 441).

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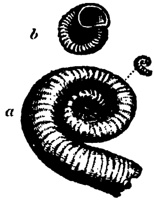
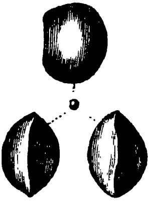
[1] Memoirs of Geol. Survey, vol. i. part i. pp. 51, 255, &c.

Fig. 438.



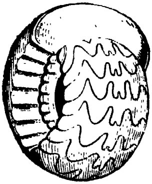
a. Microconchus (Spirorbis) carbonarius, Murch.
Nat. size and magnified.
b. Variety of same.

Fig. 439.



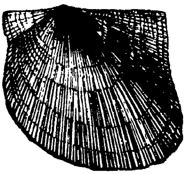
Leperditia inflata.
Nat. size and magnified.
Murchison.

Fig. 440.



Goniatites Listeri, Martin. Coal-measures, Yorkshire and Lancashire.

Fig. 441.

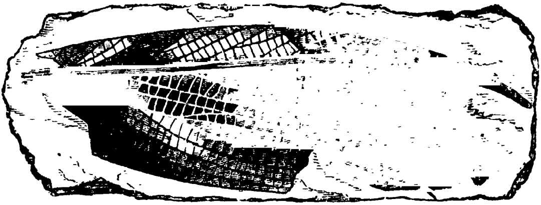


Aviculopecten papyraceus, Goldf. (*Pecten papyraceus*, Sow.)

Insects in European coal.—Articulate animals of the genus Scorpion were found by Count Sternberg in 1835 in the coal-measures of Bohemia, and about the same time in those of Coalbrook Dale by Mr. Prestwich, where also true insects such as beetles of the family *Curculionidæ*, a neuropterous insect of the genus *Corydalis*, and another related to the *Phasmidæ*, have been found.

From the coal of Wetting in Westphalia several specimens of the cockroach or *Blatta* family, and the wing of a cricket (*Acridites*), have been described by Germar. Professor Goldenberg published, in 1854, descriptions of no less than twelve species of insects from the nodular clay-ironstone of Saarbrück, near Trèves.[1] Among them are several *Blattinæ*, three species of *Neuroptera*, one beetle of the *Scarabæus* family, a grasshopper or locust, *Gryllacris* (see fig. 442), and several white ants or *Termites*. Professor Goldenberg showed me, in 1864, the wing of a white ant, found low down in the productive coal-measures of Saarbrück, in the interior of a flattened Lepidodendron. It is much larger than that of any known living species of the same genus.

Fig. 442.



Wing of a Grasshopper. *Gryllacris lithanthraca*, Goldenberg.
Coal, Saarbrück, near Trèves.

Carboniferous amphibia — Labyrinthodonts. — No vertebrated animals more highly organised than fishes were known to occur in rocks of higher antiquity than the Permian until the year 1843, when the *Apateon pedestris*, Meyer, was discovered in the coal-measures of Münster-Appel in Rhenish Bavaria.

Four years later, in 1847, Professor Von Dechen found remains of other species of Amphibia in the Saarbrück coal-field above alluded to. These were described by the late Professor Goldfuss under the generic name of *Archegosaurus*, but we owe our full and accurate knowledge of their structure to the investigations of Von Meyer. The annexed drawing shows the skull, thoracic plate, scapulæ, vertebræ, and ribs of *Archego-*

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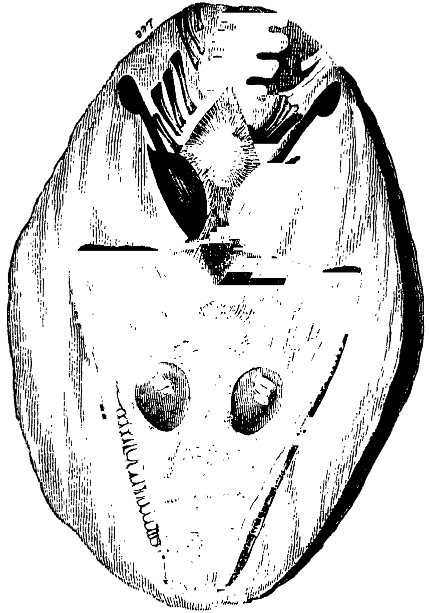
[1] Palæont. Dunker and V. Meyer, vol. iv. p. 17

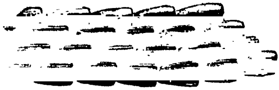
saurus Decheni. Among the more remarkable features of *Archegosaurus* are, firstly, the complete protection of the upper surface of the skull by bony plates, which fit accurately together at all stages of growth; secondly, the thoracic shield, consisting of three bony plates, of which the two outer overlap the central one; thirdly the ventral armour, composed of numerous imbricated bony scutes (fig. 444) disposed diagonally upon the under surface, between the fore and hind limbs. The teeth resemble those of *Mastodonsaurus* (p. 359), but the folding of the dentinal wall is less complex. Unlike its nearest allies, *Archegosaurus* retained throughout life imperfectly ossified or Notochordal vertebræ. The total length of a large individual may have been about seven feet.

Fig. 443.



Archegosaurus minor, Goldfuss. Fossil reptile from the coal-measures, Saarbrück.

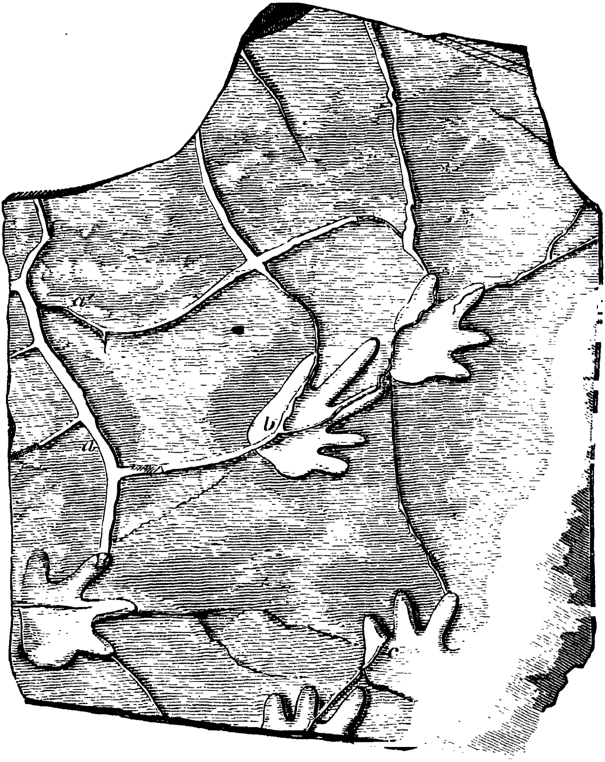
Fig. 444.



Imbricated covering of skin of *Archegosaurus medius*, Goldf. Magnified.

Some of the peculiarities of *Archegosaurus* suggest a comparison with *Crocodilia*, but its true affinity is with the Amphibia. It may be included, together with the Triassic Labyrinthodon and some Carboniferous genera to be mentioned immediately in the order Labyrinthodonta, a group co-ordinate with the recent orders, Batrachia (leaping Amphibia), Urodela (tailed Amphibia), and Gymnophiona (snake-like Amphibia), and most nearly connected with the two latter.

Fig. 445.



Scale one-sixth the original.

Slab of sandstone from the coal-measures of Pennsylvania, with footprints of air-breathing reptile and casts of cracks.

Since the first discovery of Carboniferous Labyrinthodonts in Germany, many additional genera and species have been brought to light. There are now established, according to Mr. Miall, at least seventeen genera, most of which have occurred in the British Isles, particularly in the coal-fields of Edinburgh, Glasgow, Northumberland, Kilkenny, and Staffordshire. One example has been discovered in the Yoredale Rocks of North Yorkshire.[1]

Labyrinthodont footprints in American coal-measures.—In 1844, the very year when the Apateon, before mentioned, of the coal was first met with in the country between the Moselle and the Rhine, Dr. King published an account of the footprints of a large reptile discovered by him in North America. These occur in the coal-strata of Greensburg, in Westmoreland County, Pennsylvania; and I had an opportunity of examining them when in that country in 1846. The footmarks were first observed standing out in relief from the lower surface of slabs of sandstone, resting on thin layers of fine unctuous clay. I brought away one of these masses, which is represented in the accompanying drawing (fig. 445). It displays together with footprints, the casts of cracks (*a*, *a′*) of various sizes. The origin of such cracks in clay, and casts of the same, has before been explained, and referred to the drying and shrinking of mud, and the subsequent pouring of sand into open crevices. It will be seen that some of the cracks, as at *b*, *c*, traverse the footprints, and produce distortion in them, as might have been expected, for the mud must have been soft when the animal walked over it and left the impressions; whereas, when it afterwards dried up and shrank, it would be too hard to receive such indentations.

We may assume that the reptile which left these prints on the ancient sands of the coal-measures was an air-breather, because its weight would not have been sufficient under water to have made impressions so deep and distinct. The same conclusion is also borne out by the casts of the cracks above described, for they show that the clay had been exposed to the air and sun, so as to have dried and shrunk.

Nova Scotia coal-measures.—The sedimentary strata in which thin seams of coal occur, attain a thickness, as we have seen, of 18,000 feet in the north of England exclusive of the Mountain Limestone, and are estimated by Von Dechen at over 20,000 feet in Rhenish Prussia. But the finest example in the world of a natural exposure in a continuous section ten miles long, occurs in the sea-cliffs bordering a branch of the Bay of Fundy in Nova Scotia. These cliffs, called the 'South Joggins,' which I first examined in 1842, and afterwards with Dr. Dawson in 1845, have lately been admirably described by the last-mentioned geologist[1] in detail, and his evidence is most valuable as showing how large a portion of this dense mass was formed on land, or in swamps where terrestrial vegetation flourished, or in freshwater lagoons. His computation of the thickness of the whole series of carboniferous strata as exceeding three miles, agrees with the measurement made independently by Sir William Logan in his survey of this coast.

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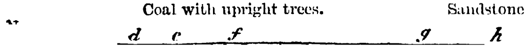
[1] L. C. Miall, Report on Labyrinthodonta, Brit. Assoc. Bradford, 1873.

There is no reason to believe that in this vast succession of strata, comprising some marine as well as many freshwater and terrestrial formations, there is any repetition of the same beds. There are no faults to mislead the geologist, and cause him to count the same beds over more than once, while some of the same plants have been traced from the top to the bottom of the whole series, and are distinct from the flora of the antecedent Devonian formation of Canada. Eighty-one seams of coal, varying in thickness from an inch to about five feet, have been discovered, and no less than seventy-one of these have been actually exposed in the sea-cliffs.

In the annexed section (fig. 446), which I examined in 1842, the beds from *c* to *i* are seen all dipping the same way, their average inclination being at an angle of 24° S.S.W. The vertical height of the cliffs is from 150 to 200 feet; and between *d* and *g*—in which space I observed seventeen trees in an upright position, or, to speak more correctly, at right angles to the planes of stratification,—I counted nineteen seams of coal, varying in thickness from 2 inches to 4 feet. At low tide a fine horizontal section of the same beds is exposed to view on the beach, which at low tide extends sometimes 200 yards from the base of the cliff. The thickness of the beds alluded to, between *d* and *g*, is about 2,500 feet, the erect trees consisting chiefly of large *Sigillariæ*, occurring at ten distinct levels, one above the other. The usual height of the buried trees seen by me was from 6 to 8 feet; but one trunk was about 25 feet high and 4 feet in diameter, with a considerable bulge at the base. In

Fig. 446.



Section of the cliffs of the South Joggins, near Minudie, Nova Scotia.

c. Grindstone. *d, g.* Alternations of sandstone, shale, and coal containing upright trees. *e, f.* Portion of cliff, given on a larger scale in fig. 447. *f.* 4-foot coal, main seam. *h, i.* Shale with freshwater mussels, see p. 411.

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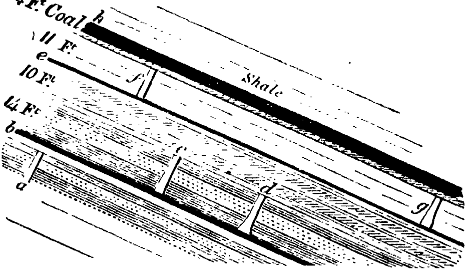
[1] Acadian Geology, 2nd edit. 1868.

no instance could I detect any trunk intersecting a layer of coal, however thin ; and most of the trees terminated downwards in seams of coal. Some few only were based on clay and shale ; none of them, except *Calamites*, on sandstone. The erect trees therefore, appeared in general to have grown on beds of vegetable matter. In the underclays *Stigmaria* abounds.

These root-bearing beds have been found under all the coal-seams, and such old soils are at present the most destructible masses in the whole cliff, the sandstones and laminated shales being harder and more capable of resisting the action of the waves and the weather. Originally the reverse was doubtless true, for in the existing delta of the Mississippi those clays in which the innumerable roots of the deciduous cypress and other swamp trees ramify in all directions are seen to withstand far more effectually the undermining power of the river, or of the sea at the base of the delta, than do beds of loose sand or layers of mud not supporting trees. It is obvious that if this sand or mud be afterwards consolidated and turned to sandstone and hard shale, it would be the least destructible.

In regard to the plants, they belong to the same genera, and most of them to the same species, as those met with in the distant coal-fields of Europe. Dr. Dawson has enumerated more than 150 species, two-thirds of which are European, a greater agreement than can be said to exist between the same Nova Scotia flora and that of the coal-fields of the United States. By referring to the section, fig. 446, the position of the four-foot coal will be perceived, and in fig. 447 (a section made by me in 1842 of a small portion) that from *e* to *f* of the same cliff is exhibited, in order to show the manner of occurrence of erect fossil trees at right angles to the planes of the inclined strata.

Fig. 447.



Erect fossil trees. Coal-measures, Nova Scotia.

In the sandstone, which filled their interiors, I frequently observed fern-leaves, and sometimes fragments of *Stigmaria*, which had evidently entered together with sediment after the trunk had decayed and become hollow, and while it was still standing under water. Thus the tree, *a*, fig. 447, represented in the bed *e* in the section, fig. 446, is a hollow trunk 5 feet 8 inches in length, traversing several strata, and cut off at the top by a layer of clay 2 feet thick, on which rests a seam of coal (*b*, fig. 447) 1 foot thick. On this coal again stood two large trees (*c* and *d*), while at a greater height the trees *f* and *g* rest upon a thin seam of coal (*e*), and above them is an underclay, supporting the 4-foot coal.

Occasionally the layers of matter in the inside of the tree are more numerous than those without; but it is more common in the coal-measures of all countries to find a cylinder of pure sandstone—the cast of the interior of a tree—intersecting a great many alternating beds of shale and sandstone, which originally enveloped the trunk as it stood erect in the water. Such a want of correspondence in the materials outside and inside, is just what we might expect if we reflect on the difference of time at which the deposition of sediment will take place in the two cases; the embedding of the tree having gone on for many years before its decay had made much progress. In many places distinct proof is seen that the enveloping strata took years to accumulate, for some of the sandstones surrounding erect sigillarian trunks support at different levels roots and stems of *Calamites*; the *Calamites* having begun to grow after the older *Sigillariæ* had been partially buried.

The general absence of structure in the interior of the large fossil trees of the Coal implies the very durable nature of their bark, as compared with their woody portion. The same difference of durability of bark and wood exists in modern trees, and was first pointed out to me by Dr. Dawson, in the forests of Nova Scotia, where the Canoe Birch (*Betula papyracea*) has such tough bark that it may sometimes be seen in the swamps looking externally sound and fresh, although consisting simply of a hollow cylinder with all the wood decayed and gone. When portions of such trunks have become submerged in the swamps they are sometimes found filled with mud. One of the erect fossil trees of the South Joggins 15 feet in height, occurring at a higher level than the main coal, has been shown by Dr. Dawson to have a coniferous structure, so that some *Coniferæ* of the Coal period grew in the same swamps as *Sigillariæ*, just as now the deciduous Cypress (*Taxodium distichum*) abounds in the marshes of Louisiana even to the edge of the sea.

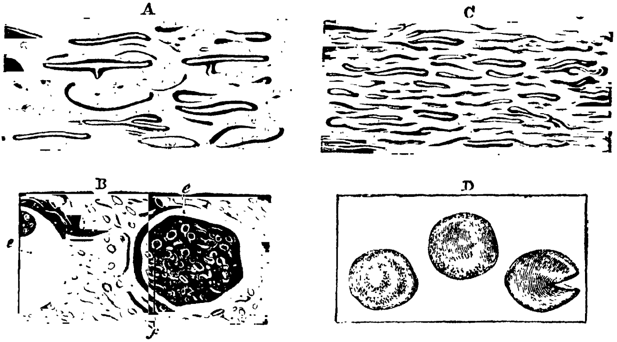
When the carboniferous forests sank below high-water mark, a species of *Spirorbis* or *Serpula* (fig. 438, p. 396), attached itself to the outside of the stumps and stems of the erect trees, adhering occasionally even to the interior of the bark—another proof that the process of envelopment was very gradual. These hollow upright trees, covered with innumerable marine annelids, reminded me of a 'cane-brake,' as it is commonly called, consisting of tall reeds, *Arundinaria macrosperma*, which I saw in 1846, at the Balize, or extremity of the delta of the Mississippi. Although these reeds are freshwater plants, they were covered with barnacles, having been killed by an incursion of salt water over an extent of many acres, where the sea had for a season usurped a space previously gained from it by the river. Yet the dead reeds, in spite of this change, remained standing in the soft mud, enabling us to conceive how easily the larger *Sigillariæ*, hollow as they were but supported by strong roots, may have resisted an incursion of the sea.

The high tides of the Bay of Fundy, rising more than 60 feet, are so destructive as to undermine and sweep away continually the whole face of the cliffs, and thus a new crop of erect fossil trees is brought into view every three or four years. They are known to extend over a space between two or three miles from north to south, and more than twice that distance from east to west, being seen in the banks of streams intersecting the coal-field.

Structure of coal.—The bituminous coal of Nova Scotia is similar in composition and structure to that of Great Britain, being chiefly derived from Sigillaroid trees mixed with leaves of ferns and of a Lycopodiaceous tree called *Cordaites* (*Noeggerathia*, &c., for genus see fig. 435, p. 383), supposed by Dawson to have been deciduous, and which had broad parallel veined leaves without a mid-rib. On the surface of the seams of coal are large quantities of mineral charcoal, which doubtless consist, as Dr. Dawson suggests, of fragments of wood which decayed in the open air, as would naturally be expected in swamps where so many erect trees were preserved. Beds of cannel-coal display, says Dr. Dawson, such a microscopical structure and chemical composition as shows them to have been of the nature of fine vegetable mud such as accumulates in the shallow ponds of modern swamps. It appears that in these cannel-coals the spore-cases of Lepidodendra are often more abundant than in the ordinary coal. Professor Huxley has ascertained that in the Better-Bed coal of Lowmoor (see A B, fig. 448) the spores and sporangia constitute a very large mass of the deposit, and this is also the case with the recent 'White

Coal' of Australia (C, fig. 448).[1] Professor Morris in 1836 *affirmed that these bodies were* the spore-cases of a plant allied

Fig. 448.



A. '*Better Bed*' Coal, from a portion unusually full of *Sporangia*, which are here shown in transverse section.
B. Same coal, section parallel with bedding; showing *Sporangia*, *e*, and spores, *f*; the latter (which are here represented somewhat too large) appear as bright rings enclosing a dark spot.
C. Australian 'White Coal,' showing *Sporangia* in transverse section.
D. External view of *Sporangia* separated from the 'White Coal.'

All these figures are enlarged about 16 diameters.

The bodies here called *Sporangia* are by some persons considered to be *Macrospores*; and those called *Spores*, to be *Microspores*.

to the living club-mosses, and Mr. Carruthers a few years ago confirmed this opinion by finding the discoidal sacs adhering to the leaves of the fossilised cone which produced them. He named the plant *Flemingites gracilis* because Professor Fleming had previously pointed out similar bodies in the coal of Scotland. Professor Huxley is inclined to believe that the English coal is largely composed of these bodies, but Principal Dawson, who has made a careful examination of the 81 coal-seams in Nova Scotia both *in situ* and in specimens under the microscope, states that 'he could only recognise the bodies called by him Sporangites in sixteen seams, and of these only four had the rounded Lycopodiaceous spore-cases similar to those of Flemingites.' He maintains, therefore, that Sporangite beds are exceptional among coals, and that cortical and woody matters are the most abundant ingredients in all the ordinary kinds, and he does not think that the coals of England are likely to prove an exception.[2] The underclays are loamy soils, which must have been sufficiently above water to admit of drainage, and the absence of sulphurates, and the occurrence of carbonate of iron in them, prove that when they existed as soils, rain-water, and not sea-water percolated them. With the exception, perhaps, of *Asterophyllites* (see fig. 469, p. 418), there is a remarkable absence from the coal-measures of any form of vegetation properly aquatic, the true coal being a sub-aërial accumulation in soil that was wet and swampy but not permanently submerged.

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[1] Huxley, Contemporary Review, 1870; and Critiques and Addresses, p. 92.

[2] Dawson, Sporecases in Coal, Silliman's Journ. of Science, 1871, p. 261.

Air-breathers of the coal.—If we have rightly interpreted the evidence of the former existence at more than eighty different levels of forests of trees, some of them of vast extent, and which lasted for ages, giving rise to a great accumulation of vegetable matter, it is natural to ask whether there were not many air-breathing inhabitants of these same regions. As yet no remains of mammalia or birds have been found, a negative character common at present to all the Palæozoic formations, but in 1852 the osseous remains of an amphibian, the first ever met with in the Carboniferous strata of the American continent, were found by Dr. Dawson and myself. We detected them in the interior of one of the erect Sigillariæ before alluded to as of such frequent occurrence in Nova Scotia. The tree was about 2 feet in diameter, and consisted of an external cylinder of bark, converted into coal, and an internal stony axis of black sandstone, or rather mud and sand stained black by carbonaceous matter, and cemented together with fragments of wood into a rock. These fragments were in the state of charcoal, and seem to have fallen to the bottom of the hollow tree while it was rotting away. The skull, jaws, and vertebræ of an amphibian, probably about 2½ feet in length (*Dendrerpeton Acadianum*, Owen), were scattered through this stony matrix. The shell, also, of a *Pupa* (see fig. 450, p. 408), the first land-shell ever met with in the coal, or in beds older than the tertiary, was observed in the same stony mass. Dr. Wyman of Boston pronounced the reptile to be allied in structure to *Monobranchus* and *Menopoma*, species of amphibians now inhabiting the North American rivers. The same view was afterwards confirmed by Professor Owen, who also pointed out the resemblance of the cranial plates to those seen in the skull of *Archegosaurus* and *Labyrinthodon*.[1] Whether the creature had crept into the hollow tree while its top was still open to the air, or whether it was washed in with mud during a flood, or in whatever other manner it entered, must be matter of conjecture.

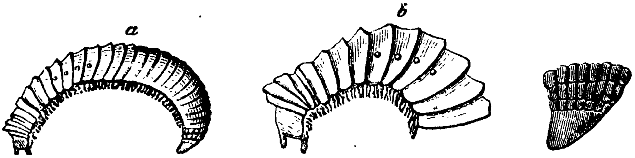
[1] Geol. Quart. Journ., vol. ix. p. 58.

Footprints of two reptiles of different sizes had previously been observed by Dr. Harding and Dr. Gesner on ripple-marked flags of the lower coal-measures in Nova Scotia (No. 2, fig. 455, p. 411), evidently made by quadrupeds walking on the ancient beach, or out of the water, just as the recent Menopoma is sometimes observed to do.

The remains of a second and smaller species of Dendrerpeton, *D. Oweni*, were also found accompanying the larger one, and still retaining some of its dermal appendages; and in the same tree were the bones of a third small lizard-like reptile, *Hylonomus Lyelli*, 7 inches long, with stout hind limbs, and fore limbs comparatively slender, supposed by Dr. Dawson to be capable of walking and running on land.[1]

In a second specimen of an erect stump of a hollow tree 15 inches in diameter, the ribbed bark of which showed that it was a Sigillaria, and which belonged to the same forest as the specimen examined by us in 1852, Dr. Dawson obtained not only fifty specimens of *Pupa vetusta* (fig. 450), and nine skeletons of reptiles belonging to four species, but also several examples of an articulated animal resembling the recent centipede or gally-worm, a creature which feeds on decayed vegetable matter (see fig. 449). Under the microscope, the head, with the eyes, mandible, and labrum are well seen. It is interesting, as being the earliest known representative of the myriapods, none of which had previously been met with in rocks older than the oolite or lithographic slate of Germany.

Fig. 449.



Xylobius Sigillariæ, Dawson. Coal, Nova Scotia and Great Britain.
a. Natural size. *b*. Anterior part, magnified. *c*. Caudal extremity, magnified.

Some years after the discovery of the first Pupa, Dr. Dawson, carefully examining the same great section containing so many buried forests in the cliffs of Nova Scotia, discovered another bed, separated from the tree containing Dendrerpeton by a mass of strata more than 1,200 feet thick. As there were 21 seams of coal in this intervening mass, the length of time comprised in the interval is not to be measured by the mere thickness of the sandstones and shales. This lower bed is an underclay 7 feet thick, with stigmarian rootlets, and the small land-shells occurring in it are in all stages of growth. They are chiefly confined to a layer about 2 inches thick, and are unmixed with any aquatic shells. They were all originally entire when imbedded, but are most of them now crushed, flattened, and distorted by pressure; they must have been accumulated, says Dr. Dawson, in mud deposited in a pond or creek.

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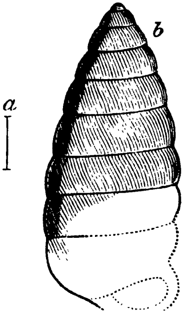
[1] Dawson, Air-Breathers of the Coal in Nova Scotia. Montreal, 1863.

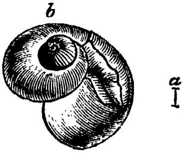
The surface striæ of *Pupa vetusta*, when magnified 50 meters, present exactly the same appearance as a portion corresponding in size of the common English *Pupa juniperi*, and the internal hexagonal cells, magnified 500 diameters, show the internal structure of the fossil and recent Pupa to be identical. In 1866[1] Dr. Dawson discovered in this lower bed, so full of the Pupa, another land-shell of the genus Helix (sub-genus Zonites) (see fig. 451).

Fig. 450.



Pupa Vetusta, Dawson.
a. Natural size.

Fig. 451.



Zonites (*Conulus*) *priscus*, Carpenter.
b. Magnified.

None of the reptiles obtained from the coal-measures of the South Joggins are of a higher grade than the labyrinthodonts, but some were of very great size, two caudal vertebræ found by Mr. Marsh in 1862 measuring two and a half inches in diameter, and implying a gigantic aquatic amphibian with a powerful swimming tail.

Except some obscure traces of an insect found by Dr. Dawson in a coprolite of a terrestrial reptile occurring in a fossil tree, no specimen of this class has been brought to light in the Joggins. But Mr. James Barnes found in a bed of shale at Little Glace Bay, Cape Breton, the wing of an Ephemera, which must have measured 7 inches from tip to tip of the expanded wings, larger than any known living insect of the Neuropterous family.

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[1] Dawson, Acadian Geology, 1868, p. 385.

That we should have made so little progress in obtaining a knowledge of the terrestrial fauna of the Coal is certainly a mystery; but we have no reason to wonder at the extreme rarity of insects, seeing how few are known in the carboniferous rocks of Europe, worked for centuries before America was discovered, and now quarried on so enormous a scale. These European rocks have not yet produced a single land-shell, in spite of the millions of tons of coal annually extracted, and the many hundreds of soils replete with the fossil roots of trees and the erect trunks and stumps preserved in the position in which they grew. In many large coal-fields we continue as much in the dark respecting the invertebrate air-breathers then living as if the coal had been thrown down in mid ocean. The early date of the Carboniferous strata cannot explain the enigma, because we know that while the land supported a luxuriant vegetation, the contemporaneous seas swarmed with life—with Articulata, Mollusca, Radiata, and Fishes. The perplexity in which we are involved when we attempt to solve this problem may be owing partly to our want of diligence as collectors, but still more perhaps to ignorance of the laws which govern the fossilisation of land-animals, whether of high or low degree.

Carboniferous rain-prints.—At various levels in the coal measures of Nova Scotia rippled-marked sandstones, and shales

Fig. 452. Fig. 453.

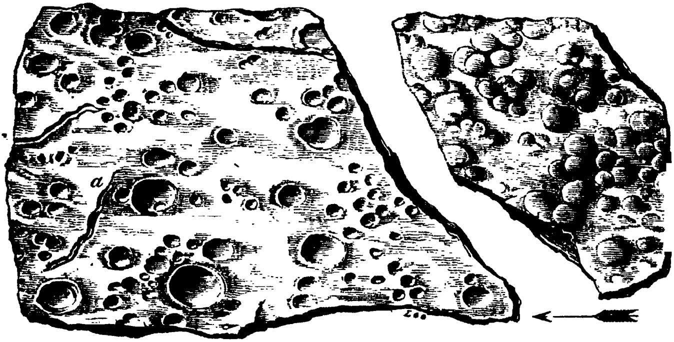


Fig. 452. Carboniferous rain-prints with worm-tracks (*a*, *b*) on green shale, from Cape Breton, Nova Scotia. Natural size.

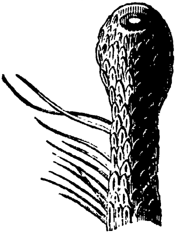
Fig. 453. Casts of rain-prints on a portion of the same slab (Fig. 452), seen to project on the under side of an incumbent layer of arenaceous shale. Natural size. The arrow represents the supposed direction of the shower.

with rain-prints, were seen by Dr. Dawson and myself, but still more perfect impressions of rain were discovered by Mr. Brown near Sydney in the adjoining island of Cape Breton. They consist of very delicate markings on greenish slates, accompanied by worm-tracks (*a*, *b*, fig. 452) such as are often seen between high and low water mark on the recent mud of the Bay of Fundy.

The great humidity of the climate of the Coal period had been previously inferred from the number of its ferns and the continuity of its forests for hundreds of miles; but it is satisfactory to have at length obtained such positive proofs of showers of rain, the drops of which resembled in their average size those which now fall from the clouds. From such data we may presume that the atmosphere of the Carboniferous period corresponded in density with that now investing the globe, and that different currents of air varied then as now in temperature, so as to give rise, by their mixture, to the condensation of aqueous vapour.

Folding and denudation of the beds indicated by the Nova Scotia coal-strata.—The series of events which are indicated by the great section of the coal-strata in Nova Scotia consist of a gradual and long-continued subsidence of a tract which throughout most of the period was in the state of a delta, though occasionally submerged beneath a sea of moderate depth. Deposits of mud and sand were first carried down into a shallow sea on the low shores of which the foot-prints of reptiles were sometimes impressed (see above, p. 400). Though no regular seams of coal were formed, the characteristic imbedded coal-plants are of the genera *Cyclopteris* and *Alethopteris*, agreeing with species occurring at much higer levels, and distinct from those of the antecedent Devonian group. The *Lepidodendron corrugatum* (see fig. 454), a plant predominating in the Lower Carboniferous group of Europe, is also conspicuous in these shallow-water beds, together with many fishes and entomostracans. A more rapid rate of subsidence sometimes converted part of the sea into deep clear water, in which there was a growth of coral which was afterwards turned into crystalline limestone, and parts of it, apparently by the action of sulphuric acid, into gypsum. In spite of continued sinking, amounting to several thousand feet, the sea might in time have been rendered shallow

Fig. 454.



Cone and branch of *Lepidodendron corrugatum*. Lower Carboniferous, New Brunswick.

by the growth of coral, had not its conversion into land or swampy ground been accelerated by the pouring in of sand and the advance of the delta accompanied with such fluviatile and brackish-water formations as are common in lagoons.

The amount to which the bed of the sea sank down in order to allow of the formation of so vast a thickness of rock of sedimentary and organic origin is expressed by the total thickness of the Carboniferous strata, including the coal-measures, No. 1, and the rocks which underlie them, No. 2, fig. 455.

Fig. 455.

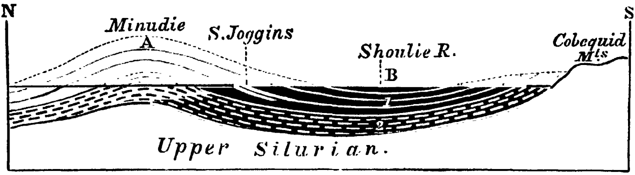


Diagram showing the curvature and supposed denudation of the Carboniferous strata in Nova Scotia.

A. Anticlinal axis of Minudie. B. Synclinal of Shoulie River.
1. Coal-measures. 2. Lower Carboniferous.

After the strata No. 2 had been elaborated, the conditions proper to a great delta exclusively prevailed, the subsidence still continuing so that one forest after another grew and was submerged until their underclays with roots, and usually seams of coal, were left at more than eighty distinct levels. Here and there also deposits bearing testimony to the existence of fresh or brackish-water lagoons, filled with calcareo-bituminous mud, were formed. In these beds (*h* and *i*, fig. 446, p. 401) are found freshwater bivalves or mussels allied to Anodon, though not identical with that or any living genus, and called *Naiadites carbonarius* by Dawson. They are associated with small entomostracous crustaceans of the genus Cythere, and scales of small fishes. Occasionally some of the calamite brakes and forests of Sigillariæ and Coniferæ were exposed in the flood season, or sometimes, perhaps by slight elevatory movements, to the denuding action of the river or the sea.

In order to interpret the great coast section exposed to view on the shores of the Bay of Fundy (fig. 455), the student must in the first place understand that the newest or last-mentioned coal formations would have been the only ones known to us (for they would have covered all the others), had there not been two great movements in opposite directions, the first consisting of a general sinking of three miles, which took place during the Carboniferous period, and the second, an upheaval of more limited horizontal extent, by which the anticlinal axis A was formed. That the first great change of level was one of subsidence is proved by the fact that there are shallow-water deposits at the base of the Carboniferous series, or in the lowest beds of No. 2.

Subsequent movements produced in the Nova Scotia and the adjoining New Brunswick coal-fields the usual anticlinal and synclinal flexures. In order to follow these we must survey the country for about thirty miles round the South Joggins, or the region where the erect trees described in the foregoing pages are seen. As we pass along the cliffs for miles in a southerly direction, the beds containing these fossil trees, which were mentioned as dipping about 18° south, are less and less inclined until they become nearly horizontal in the valley of a small river called the Shoulie, as ascertained by Dr. Dawson. After passing this synclinal line the beds begin to dip in an opposite or north-easterly direction, acquiring a steep dip where they rest unconformably on the edges of the Upper Silurian strata of the Cobequid Hills, as shown in fig. 455. But if we travel northwards towards Minudie from the region of the coal-seams and buried forests, we find the dip of the coal-strata increasing from an angle of 18° to one of more than 40°, lower beds being continually exposed to view till we reach the anticlinal axis A and see the lower Carboniferous formation No. 2, at the surface. The rocks removed by denudation are expressed by the faint lines at A; and thus the student will see that, according to the principles laid down in the seventh chapter, we are enabled, by the joint operations of upheaval and denudation, to look, as it were, about three miles into the interior of the earth without passing beyond the limits of a single formation.

CHAPTER XXIV.

FLORA AND FAUNA OF THE CARBONIFEROUS PERIOD.

Vegetation of the Coal period—Ferns, Lycopodiaceæ, Equisetaceæ, Sigillariæ, Stigmariæ, Coniferæ—Monocotyledon of the coal-measures—Climate of the Coal period—Mountain Limestone—Marine Fauna of the Carboniferous Period—Corals—Polyzoa, Crinoidea—Mollusca—Great number of fossil fish—Foraminifera.

Vegetation of the Coal period.—In the last chapter we have seen that the seams of coal, whether bituminous or anthracitic, are derived from the same species of plants, and Göppert has ascertained that the remains of every family of plants scattered through the shales and sandstones of the coal-measures are sometimes met with in the pure coal itself—a fact which adds greatly to the geological interest of this flora.

The Coal period was called by Adolphe Brongniart the age of Acrogens,[1] so great appears to have been the numerical preponderance of flowerless or cryptogamic plants of the families of ferns, club-mosses, and horse-tails. He reckoned the known species in 1849 at 500, and the number has been largely increased by recent search in spite of reductions owing to the discovery that different parts of even the same plants had been taken for distinct species. Notwithstanding these changes, Brongniart's generalisation concerning this flora still holds true, namely, that the state of the vegetable world was then extremely different from that now prevailing, not only because the cryptogamous plants constituted nearly the whole flora, but also because they were on the whole more highly developed than any belonging to the same class now existing, and united some forms of structure now only found separately and in distinct orders. The only phænogamous plants which constitute any feature in the coal are the coniferæ; monocotyledons appear to have been very rare, and angiospermous dicotyledons, with one or two doubtful exceptions, were wanting. For this we are in some measure prepared by what we have seen of the Secondary or Mesozoic floras if, consistently with the belief in the theory of evolution, we expect to find the prevalence of simpler and less specialised organisms in older rocks.

Ferns.—We are struck at the first glance with the similarity of the ferns to those now living. In the fossil genus *Pecopteris*, for example (fig. 456), it is not easy to decide whether the fossils might not be referred to the same genera as those established for living ferns; whereas, in regard to some of the other contemporary families of plants, with the exception of the fir-tribe, it is not easy to guess even the class to which they belong. The ferns of the Carboniferous period are generally without organs of fructification, but in the few instances in which these do occur in a fit state for microscopical investigations they agree with those of the living ferns.

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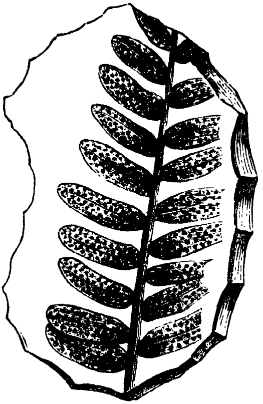
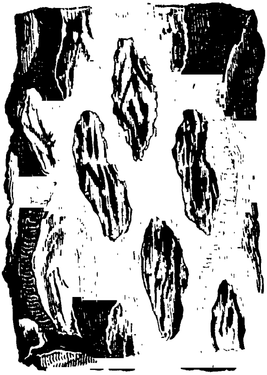
[1] For botanical nomenclature, see p. 287.

Fig. 456.



Pecopteris elliptica, Bunbury.[1] Frostburg.

Fig. 457.



Caulopteris primæva, Lindley.

When collecting fossil specimens from the coal-measures of Frostburg in Maryland, I found in the iron-shales several species with well-preserved rounded spots or marks of the sori (see fig. 456). In the general absence of such characters they have been divided into genera, distinguished chiefly by the branching of the fronds and the way in which the veins of the leaves are disposed. The larger portion are supposed to have been of the size of ordinary European ferns, but some were decidedly arborescent, especially the group called *Caulopteris* (see fig. 457) by Lindley, and the *Psaronius* of the upper or newest coal-measures, before alluded to (p. 384). All the recent tree-ferns belong to one tribe (*Polypodiaceæ*), and to a small number only of genera in that tribe, in which the surface of the trunk is marked with scars, or cicatrices, left after the fall of the fronds. These scars resemble those of *Caulopteris.*

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[1] Sir C. Bunbury, Geol. Quart. Journ., vol. ii. 1845.

No less than 130 species of ferns are enumerated as having been obtained from the British coal-strata, and this number is more than doubled if we include the Continental and American species. Even if we make some reduction on the ground of varieties which have been mistaken, in the absence of their fructification, for species, still the result is singular, because the whole of Europe affords at present no more than sixty-seven indigenous species.

Fig. 459.

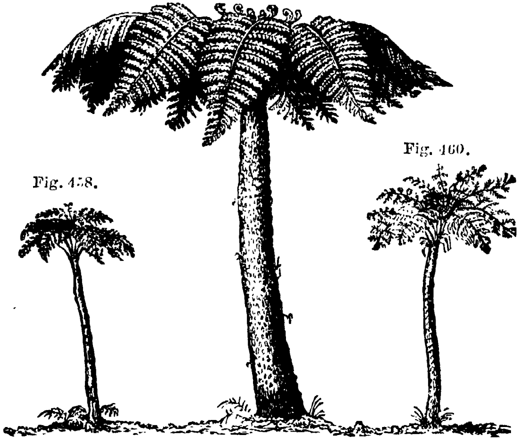


Fig. 458.

Fig. 460.

Living tree-ferns of different genera. (Ad. Brong.)
Fig. 458. Tree-fern from Isle of Bourbon.
459. *Cyathea glauca*, Mauritius.
460. Tree-fern from Brazil.

Lycopodiaceæ.—*Lepidodendron.*—About forty species of fossil plants of the Coal have been referred to this genus, more than half of which are found in the British coal-measures. They consist of cylindrical stems or trunks, covered with leaf-scars. In their mode of branching, they are always dichotomous (see fig. 462). They belong to the *Lycopodiaceæ*, bearing sporangia and spores similar to those of the living representatives of this family (fig. 465); and although most of the Carboniferous species grew to the size of large trees, Mr. Carruthers has found by careful measurement that the volume of the fossil spores did not exceed that of the recent club-moss—a fact of some geological importance, as it may help to explain the facility with which these seeds may have been transported by the wind, causing the same wide distribution of the species of the fossil forests in Europe and America which we now observe in the geographical distribution of so many living families of cryptogamous plants. The figs. 461–463 represent a fossil *Lepidodendron*, 49 feet long, found in Jarrow Colliery, near Newcastle, lying in shale parallel to the planes of stratification. Fragments of others, found in the same shale, indicate, by the size of the rhomboidal scars which cover them, a still greater

Fig. 461.

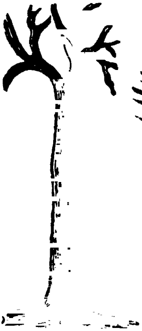


Fig. 462.

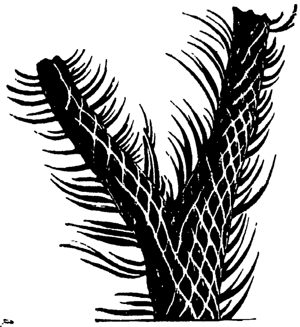
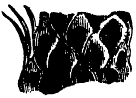
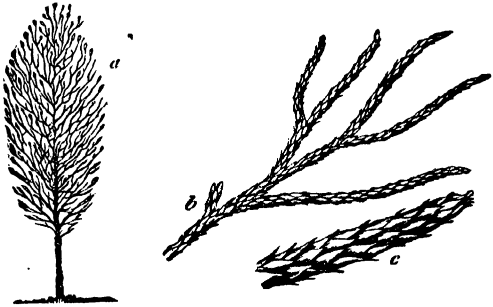


Fig. 463.



Lepidodendron Sternbergii. Coal-measures, near Newcastle.
Fig. 461. Branching trunk, 49 feet long, supposed to have belonged to *L. Sternbergii.* (Foss. Flo. 203.)
462. Branching stem with bark and leaflets of *L. Sternbergii.* (Foss. Flo. 4.)
463. Portion of same nearer the root. Natural size. (Ibid.)

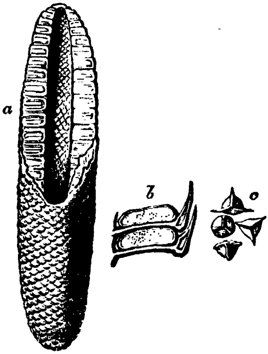
Fig. 464.



a. Lycopodium densum. Living species. New Zealand.
b. Branch; natural size. *c.* Part of same, magnified.

magnitude. The living club-mosses, of which there are about 200 species, are most abundant in tropical climates. They usually creep on the ground, but some stand erect, as the *Lycopodium densum* from New Zealand (fig. 464), which attains a height of three feet.

Fig. 465.

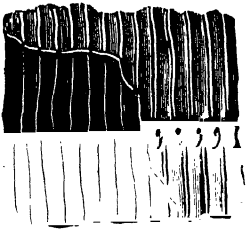


a. Lepidostrobus ornatus, Brong. (Strobilus or cone), Shropshire; ½ nat. size.
b. Portion of a section showing the large sporangia in their natural position.
c. Microspores occurring in these sporangia, highly magnified.[1]

In the Carboniferous strata of Coalbrook Dale, and in many other coal-fields, elongated cylindrical bodies, called fossil cones, and named *Lepidostrobus* by M. Adolphe Brongniart, are met with (see fig. 465). They often form the nucleus of concretionary balls of clay-ironstone, and are well preserved, exhibiting a conical axis, around which a great quantity of scales were compactly imbricated. The opinion of M. Brongniart, that the *Lepidostrobus* is the fruit of *Lepidodendron* has been confirmed, for these *strobili* or fruits have been found terminating the tips of branches of well-characterised *Lepidodendra* in Coalbrook Dale and elsewhere.

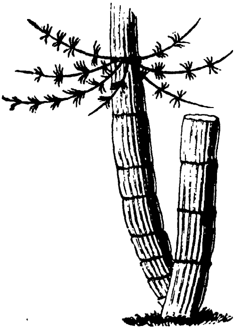
Equisetaceæ.—To this family belong two fossil genera of the

Fig. 466.



Calamites Sucowii, Brong.; natural size. Common in coal throughout Europe.

Fig. 467.



Stem of fig. 466, as restored by Dr. Dawson.

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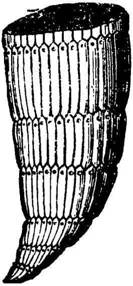
[1] Hooker, Mem. Geol. Survey, vol. ii. part 2, p. 440.

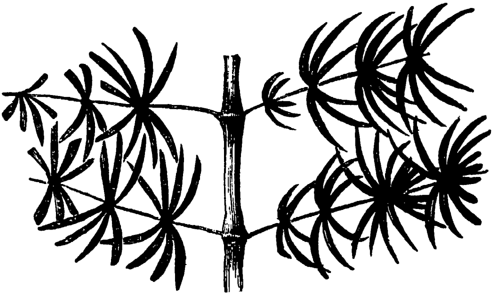
coal, *Equisetites* and *Calamites*. The Calamites were evidently closely related to the modern horse-tails (Equiseta), differing in their great size, the want of sheaths at the joints, and some details of fructification, and especially in the more complex and highly-organised structure of the woody zone resembling in appearance the structure of exogenous plants. They grew in dense brakes on sandy and muddy flats in the manner of modern Equisetaceæ, and their remains are frequent in the coal. Seven species of this plant occur in the great Nova Scotia section before described, where the stems of some of them five inches in diameter, and sometimes eight feet high, may be seen terminating downwards in a tapering root. Fig. 468 represents an inorganic cast of the internal cavity of a Calamite stem, the ridges and furrows being impressions of the inner surface of the woody zone. The little tubercles seen near the articulations appear to be the scars of broken bundles of vessels.

Fig. 468.



Radical termination of a Calamite. Nova Scotia.

Fig. 469.

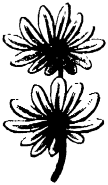


Asterophyllites foliosus. (Foss. Flo. 25.) Coal-measures, Newcastle.

Botanists are not yet agreed whether the *Asterophyllites* (see fig. 469) was the foliage of Calamites or not. Professor Williamson, from the microscopical examination of the internal structure of many well-preserved specimens, has come to the conclusion that the *Asterophyllites* did not belong even to the same natural order with the Calamites, but formed a distinct group, likewise Cryptogamous, but more nearly related to the Lycopodiums than to the Equisetums. Dr. Dawson inclines to the same view from the presence of a mid-rib in the leaves of Asterophyllites, which is wanting in the leaves known to belong to some Calamites. Professor Schimper and Mr. Carruthers, however, consider that Asterophyllites is the foliage of the Calamite, and the latter even contends that he has found the leaves attached to a Calamite stem.

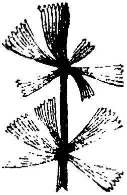
Figs. 470 and 471 represent leaves of *Annularia* and *Sphenophyllum*, common in the coal, and believed by Mr. Carruthers to be leaves of Calamites. There is still a difference of opinion as to whether these forms are or are not closely allied to *Asterophyllites*. Dr. Williamson, who has carefully studied the Calamites, thinks that they had a fistular pith, exogenous woody stem, and thick smooth bark, which last having always disappeared, leaves a fluted stem as represented in fig. 467.

Fig. 470.



Annularia sphenophylloides, Zenker.

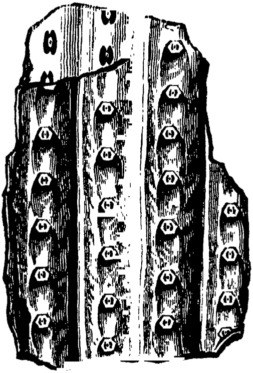
Fig. 471.



Sphenophyllum erosum, Lindley and Hutton.

Sigillaria.—A large portion of the trees of the Carboniferous period belonged to this genus, of which as many as twenty-eight species are enumerated as British. The structure, both internal and external, was very peculiar, and, with reference to existing types, very anomalous. They were formerly referred, by M. Ad. Brongniart, to ferns, which they resemble in the scalariform texture of their vessels, and in some degree in the form of the cicatrices left by the base of the leaf-stalks which have fallen off (see fig. 472). But some of them are ascertained to have had long linear leaves, quite unlike those of ferns. They grew to a great height, from 30 to 60, or even 70 feet, with regular cylindrical stems, and without branches, although some species were dichotomous towards the top. Their fluted trunks, from one to five feet in diameter, appear to have decayed more rapidly in

Fig. 472.



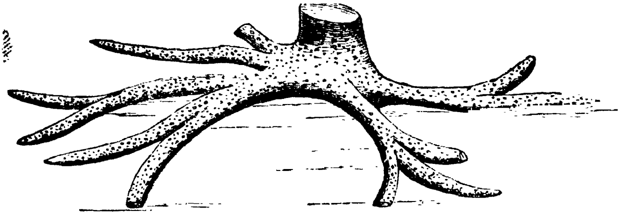
Sigillaria lævigata, Brong.

the interior than externally, so that they became hollow when standing; and when thrown prostrate, they were squeezed down and flattened. Hence, we find the bark of the two opposite sides (now converted into bright shining coal) constitute two horizontal layers, one upon the other, half an inch, or an inch, in their united thickness. These same trunks, when they are placed obliquely or vertically to the planes of stratification, retain their original rounded form, and are uncompressed, the cylinder of bark having been filled with sand, which now affords a cast of the interior.

Dr. Hooker inclined to the belief that the *Sigillariæ* may have been cryptogamous, though more highly developed than any flowerless plants now living. Dr. Dawson having found in some species what he regards as medullary rays, thinks with Brongniart that they have some relation to gymnogens, while Mr. Carruthers leans to the opinion that they belong to the Lycopodiaceæ.

Stigmaria.—This fossil, the importance of which has already been pointed out (p. 389), was originally conjectured to be an aquatic plant. It is now ascertained to be the root of *Sigillaria.* The connection of the roots with the stem, previously suspected, on botanical grounds, by Brongniart, was first proved, by actual contact, in the Lancashire coal-field, by Mr. Binney. The fact has lately been shown, even more distinctly, by Mr. Richard Brown, in his description of the *Stigmariæ* occurring in the underclays of the coal-seams of the Island of Cape Breton, in Nova Scotia. In a specimen of one of these, represented in the annexed figure (fig. 473), the spread of the roots was sixteen feet, and some of them sent out rootlets, in all directions, into the surrounding clay. Mr. Richard Brown also found Stigmarian roots in the coal-field of Cape Breton attached to trees believed by him to be Lepidodendra, and Mr. Carruthers has confirmed this opinion from specimens of Lepidodendron occurring

Fig. 473.

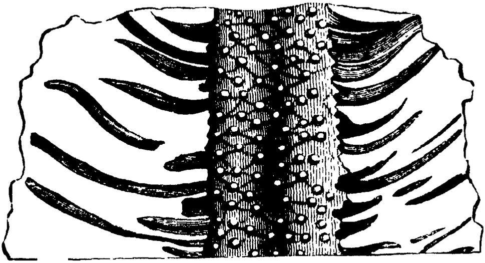


Stigmaria attached to a trunk of *Sigillaria.*

in British coal-fields. These facts are of great importance as helping to prove the affinity of *Sigillaria* and *Lepidodendron*, and thus confirming the opinion that the latter belong to the Lycopodiaceæ.

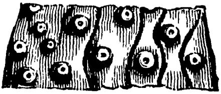
In the sea-cliffs of the South Joggins in Nova Scotia, I examined several erect *Sigillariæ*, in company with Dr. Dawson, and we found that from the lower extremities of the trunk they sent out *Stigmariæ* as roots. All the stools of the fossil trees dug out by us divided into four parts, and these again bifurcated, forming eight roots, which were also dichotomous when traceable far enough. The cylindrical rootlets formerly regarded as leaves are now shown by more perfect specimens to have been attached to the root by fitting into deep cylindrical pits. In the fossil there is rarely any trace of the form of these cavities, in consequence of the shrinkage of the surrounding tissues. Where the rootlets are removed nothing remains on the surface of the Stigmaria but rows of mammillated tubercles (see figs. 474, 475), which have formed the base of each rootlet. These protuberances may possibly indicate the place of a joint at the lower extremity of the rootlet. Rows of these tubercles are arranged spirally round each root, which have always a medullary axis and woody system much resembling that of *Sigillaria*, the structure of the vessels being, like it, scalariform. No instance seems yet to have been met with in Nova Scotia of Stigmarian roots attached to Lepidodendron.

Fig. 474.



Stigmaria ficoides, Brong. ⅓ natural size. (Foss. Flo. 32.)

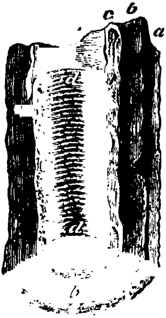
Fig. 475.



Surface of another individual of same species, showing form of tubercles. (Foss. Flo. 34.)

Coniferæ.—The coniferous trees of this period are referred to five genera; the woody structure of some of them showing that they were allied to the Araucarian division of pines, more than to any of our common European firs. Some of their trunks exceeded forty-four feet in height. Many, if not all of them, seem to have differed from living *Coniferæ* in having large piths; for Professor Williamson has demonstrated the fossil of the coal-measures called *Sternbergia* to be the pith of these trees, or rather the cast of cavities formed by the shrinking or partial absorption of the original medullary axis (see figs. 476, 477).

Fig. 476.

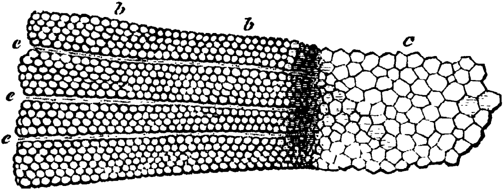


Fragment of coniferous wood, *Dadoxylon*, of Endlicher, fractured longitudinally; from Coalbrook Dale. W. C. Williamson.[1]

a. Bark.
b. Woody zone or fibre (pleurenchyma).
c. Medulla or pith,
d. Cast of hollow pith or 'Sternbergia.'

This peculiar type of pith is observed in living plants of very different families, such as the common Walnut and the White Jasmine, in which the pith becomes so reduced as simply to form a thin lining of the medullary cavity, across which transverse plates of pith extend horizontally, so as to divide the cylindrical hollow into discoid interspaces. When these interspaces have been filled up with inorganic matter, they constitute an axis to which, before their true nature was known, the provisional name of *Sternbergia* (*d*, *d*, fig. 476) was given. In the

Fig. 477.



Magnified portion of fig. 476; transverse section.
c. Pith. *b*, *b*. Woody fibre. *e*, *e*. Medullary rays.

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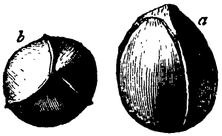
[1] Manchester Phil. Mem., vol. ix. 1851.

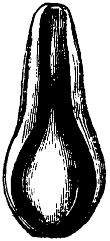
above specimen the structure of the wood (*b*, figs. 476 and 477) is coniferous, and the fossil is referable to Endlicher's fossil genus *Dadoxylon*.

Fig. 478.



Trigonocarpum ovatum, Lindley and Hutton. Peel Quarry, Lancashire.

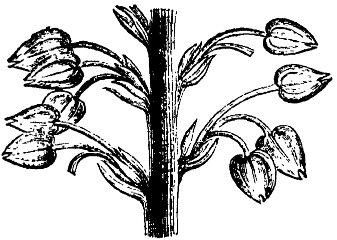
Fig. 479.



Trigonocarpum olivæforme, Lindley, with its fleshy envelope. Felling Colliery, Newcastle.

The fossil named *Trigonocarpum* (figs. 478 and 479), formerly supposed to be the fruit of a palm, may now, according to Dr. Hooker, be referred, like the *Sternbergia*, to the *Coniferæ*. Its geological importance is great, for so abundant is it in the coal-measures that in certain localities the fruit of some species may be procured by the bushel; nor is there any part of the formation where they do not occur, except the underclays and limestone. The sandstone, ironstone, shales, and coal itself, all contain them. Mr. Binney has at length found in the clay-ironstone of Lancashire several specimens displaying structure, and from these, says Dr. Hooker, we learn that the *Trigonocarpum* belonged to that large section of existing coniferous plants which bear fleshy solitary fruits, and not cones. It resembled very closely the fruit of the Chinese genus, *Salisburia*, one of the Yew tribe, or Taxoid conifers.

Fig. 480.



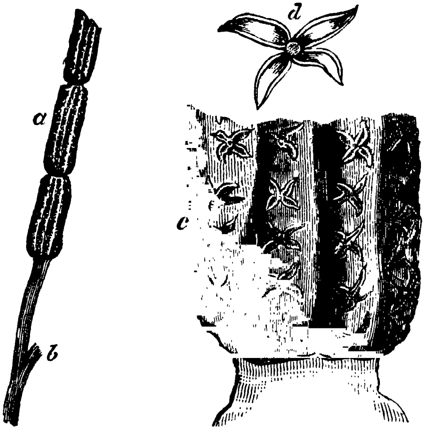
Cardiocarpon Lindleyi, Carr. (*Antholithes*, Lind.) Coal-measures, Falkirk.

The curious fossils called *Antholithes* by Lindley, which were formerly considered to be flower-spikes, are probably allied to the Coniferæ. No specimen has yet been found exhibiting structure, so that their true position is somewhat doubtful; but Mr. Peach in 1870 obtained specimens from carboniferous shales near Falkirk (fig. 480), in which the fruit was attached to the stem, and Mr.

Carruthers has ascertained that these fruits are identical with others found in the coal-measures by Brongniart, and named by him *Cardiocarpon*. The processes supposed by Lindley to be petals prove to be pedicels of the fruit springing from each cluster of leaves on the axis. The fruit itself is flat and broadly ovate, with a cordate base, and a somewhat acute bifid apex.[1]

Monocotyledon in the coal-measures.—In the coal-measures of Granton, near Edinburgh, a remarkable fossil (fig. 481) was found and described in 1840[2] by Dr. Robert Paterson. It was compressed between layers of bituminous shale, and consists of a stem bearing a cylindrical spike *a*, which in the portion preserved in the slate exhibits two subdivisions and part of a third. The spike is covered on the exposed surface with the four-cleft calyces of the flowers arranged in parallel rows. The stem shows, at *b*, a little below the spike, remains of a lateral appendage, which is supposed to indicate the beginning of the spathe. The fossil has been referred to the *Aroidiæ*, and there is every probability that it is a true member of this order. There can at least be no doubt as to the high grade of its organisation and that it belongs to the monocotyledons. Mr. Carruthers has

Fig. 481.



Pothocites Grantonii, Pat. Coal-measures, Edinburgh.
a. Stem and spike ; ½ nat. size.
b. Remains of the spathe, magnified.
c. Portion of spike, magnified.
d. One of the calyces, magnified.

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[1] Carruthers, Notes on Fossil Plants, Geol. Mag., vol. ix. 1872, p. 54.

[2] Trans. of Bot. Soc. Edinburgh, vol. i. 1844.

carefully examined the original specimen in the Botanical Museum, Edinburgh, and thinks it may have been an epiphyte.

Climate of the Coal Period.—As to the climate of the Coal, the Ferns and the Coniferæ are perhaps the two classes of plants which may be most relied upon as leading us to safe conclusions, as the genera are nearly allied to living types. All botanists admit that the abundance of ferns implies a moist atmosphere. But the coniferæ, says Hooker, are of more doubtful import, as they are found in hot and dry and in cold and dry climates, in hot and moist and in cold and moist regions. In New Zealand the coniferæ attain their maximum in numbers constituting $\frac{1}{62}$ part of all the flowering plants ; whereas in a wide district around the Cape of Good Hope they do not form $\frac{1}{1600}$ of the phenogamic flora. Besides the conifers, many species of ferns flourish in New Zealand, some of them arborescent, together with many lycopodiums ; so that a forest in that country may make a nearer approach to the carboniferous vegetation than any other now existing on the globe.

MARINE FAUNA OF THE CARBONIFEROUS PERIOD.

It has already been stated that the Carboniferous or Mountain Limestone underlies the coal-measures in the south of England and Wales, whereas in the North and in Scotland marine calcareous rocks partly of the age of the Mountain Limestone alternate with shales and sandstones, containing seams of coal. In its most calcareous form the Mountain Limestone is destitute of land-plants, and is loaded with marine remains—the greater part, indeed, of the rock, being made up bodily of crinoids, corals, and polyzoa with interspersed mollusca.

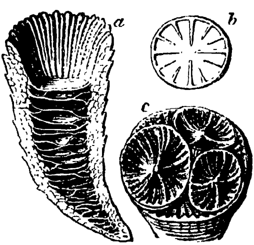
Corals.—The Corals deserve especial notice, as the cup-and-star corals, which have the most massive and stony skeletons, display peculiarities of structure by which they may be distinguished generally, as MM. Milne Edwards and Haime first pointed out, from all species found in strata newer than the Permian. There is, in short, an ancient or *Palæozoic*, and a modern or *Neozoic* type, if by the latter term we designate (as proposed by Prof. E. Forbes) all strata from the triassic to the most modern, inclusive. The accompanying diagrams (figs. 482, 483) may illustrate these types.

It will be seen that the more ancient corals have what is called a quadripartite arrangement of the chief vertical plates or *lamellæ*—parts of the skeleton which support the organs of reproduction. The number of these lamellæ in the Palæozoic type is 4, 8, 16, &c. ; while in the Neozoic type the number is

6, 12, 24, or some other multiple of six; and this holds good, whether they be simple forms, as in fig. 482, *a* and 483, *a*, or aggregate clusters of corallites, as in 482, *c*. But further investigations have shown in this, as in all similar grand generalisations in natural history, that there are exceptions to the rule.

Fig. 482.

Palæozoic type of lamelliferous cup-shaped Coral. Order ZOANTHARIA RUGOSA, Milne Edwards and Jules Haime.



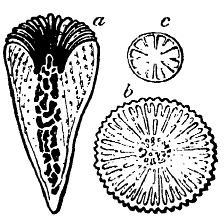
a. Vertical section of *Campophyllum flexuosum* (*Cyathophyllum*, Goldfuss); ½ nat. size: from the Devonian of the Eifel. The *lamellæ* are seen around the inside of the cup; the walls consist of cellular tissue; and large transverse plates, called *tubulæ*, divide the interior into chambers.

b. Arrangement of the *lamellæ* in *Polycælia profunda*, Germar, sp.; nat. size: from the Magnesian Limestone, Durham. This diagram shows the quadripartite arrangement of the primary septa, characteristic of palæozoic corals, there being 4 principal and 8 intermediate lamellæ. the whole number in this type being always a multiple of four.

c. *Stauria astræiformis*, Milne Edwards. Young group, nat. size. Upper Silurian, Gothland. The lamellæ or septal system in each cup are divided by four prominent ridges into four groups.

Thus in the Lower Greensand *Holocystis elegans* (Ed. and H.) and other forms have the Palæozoic type, and Dr. Duncan has shown to what extent the Neozoic forms penetrate downwards into the Carboniferous and Devonian rocks.

Neozoic type of lamelliferous cup-shaped Coral. Order ZOANTHARIA APOROSA, M. Edwards and J. Haime.



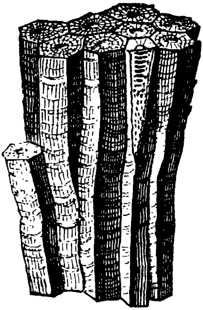
a. *Parasmilia centralis*, Mantell, sp. Vertical section; nat. size. Upper Chalk, Gravesend. In this type the *lamellæ* are massive, and extend to the axis or columella composed of loose cellular tissue, without any transverse plates like those in fig. 482, *a*.

b. *Cyathina Bowerbankii*, Ed. and H. Transverse section, enlarged. Gault, Folkestone. In this coral the primary septa are a multiple of six. The twelve principal plates reach the columella, and between each pair there are three secondaries, in all forty-eight. The short intermediate plates which proceed from the columella are not counted. They are called *pali*.

c. *Fungia patellaris*, Lamk. Recent; very young state. Diagram of its six primary and six secondary septa, magnified. The sextuple arrangement is always more manifest in the young than in the adult state.

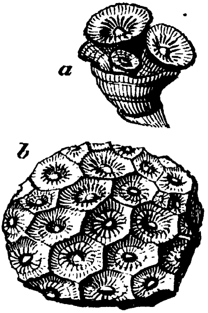
From a great number of rugose lamelliferous corals met with in the Mountain Limestone, two species (fig. 484, 485) have been selected, as having a very wide range, extending from the eastern borders of Russia to the British Isles, and being found almost everywhere in each country. These fossils, together with numerous species of *Zaphrentis, Amplexus, Cyathophyllum,* and *Clisiophyllum,* form a group of rugose corals widely different from any that followed them. With them are associated certain tabulate corals, especially *Michelinia* and *Syringopora,* the latter of which often formed small reefs.[1]

Fig. 484.



Lithostrotion basaltiforme, Phil. sp. (*Lithostrotion striatum,* Fleming; *Astræa basaltiformis,* Conyb. and Phill.). England; Ireland; Russia; Iowa, and westward of the Mississippi, United States. (Dr. D. Owen.)

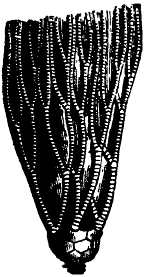
Fig. 485.



Lonsdaleia floriformis (Martin, sp.), M. Edwards. (*Lithostrotion floriforme,* Fleming. *Strombodes*).
a. Young specimen, with buds or corallites on the disk, illustrating calicular gemmation. *b.* Part of a full-grown compound mass. Bristol, &c.; Russia.

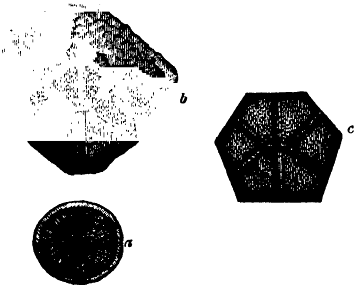
Polyzoa and Crinoidea.—Of the *Polyzoa,* the prevailing forms are *Fenestella, Hemitrypa,* and *Polypora,* and these often

Fig. 486.



Cyathocrinus planus. Miller.
Body and arms.
Mountain Limestone.

Fig. 487.



Cyathocrinus caryocrinoides, M'Coy.
a. Surface of one of the joints of the stem.
b. Pelvis or body; called also calyx or cup.
c. One of the pelvic plates.

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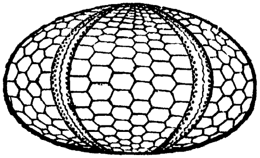
[1] For figures of these corals, see Palæontographical Society's Monographs, 1852.

form considerable beds. Their net-like fronds are easily recognised. *Crinoidea* are also numerous in the Mountain Limestone (see figs. 486, 487).

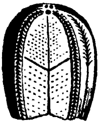
In the greater part of them, the cup or pelvis (fig. 487 *b*) is greatly developed in size in proportion to the arms, although this is not the case in fig. 486. The genera *Poteriocrinus*, *Cyathocrinus Actinocrinus*, and *Platycrinus*, are all of them characteristic of this formation. Other Echinoderms are rare, a few Sea-Urchins only being known: these have a complex structure, with many more interambulacral plates than are seen in the modern genera of the same group. One genus, the *Palæchinus* (fig. 488), is the analogue of the modern *Echinus*, but has four, five, or six rows of plates in the interambulacral region or area, whereas the modern genera have only two.

Fig. 488.



Palæchinus gigas, M'Coy. Reduced one third. Carboniferous Limestone. Ireland.

Fig. 489.



Pentremites ellipticus, Sow. Carb. Limestone, Derbyshire, &c.

The other, *Archæocidaris*, represents, in like manner, the *Cidaris* of the present seas. Two genera of Blastoidea, *Pentremites* and *Codonaster*, are peculiar to this formation in Europe and North America. *Pentremites* (fig. 489) is much the most abundant genus, and like *Codonaster* is distinguished from the true Crinoids and Cystoidea by the absence of arms.

Mollusca.—The British Carboniferous Mollusca enumerated by Mr. Etheridge[1] comprise 653 species referable to 86 genera, occurring chiefly in the Mountain Limestone. Of this large number only 40 species are common to the underlying Devonian rocks, 9 of them being Cephalopods, 7 Gasteropods, and the rest bivalves, chiefly Brachiopoda (Palliobranchiata). This latter group constitutes by far the larger part of the Carboniferous Mollusca, 157 species being known in Great Britain alone, and it will be found to increase in importance in the fauna of the Silurian rocks, especially in the Wenlock and Caradoc series. Perhaps the most characteristic shells of the formation are large species of *Productus*, such as *P. giganteus*, *P. semireticulatus*

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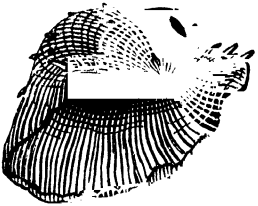
[1] Quart. Geol. Journ., vol. xxiii. p. 674. 1867.

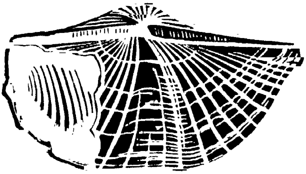
(fig. 490), and *P. scabriculus.* Large plaited spirifers, as *Spirifera striata, S. rotundata,* and *S. trigonalis* (fig. 491), also

Fig. 490.



Productus semireticulatus, Martin, sp. (*P. antiquatus,* Sow.) Carboniferous Limestone. England; Russia; the Andes; &c.

Fig. 491.

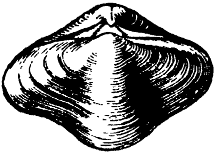


Spirifera trigonalis, Martin, sp. Carboniferous Limestone. Derbyshire, &c.

abound; and smooth species, such as *Spirifera glabra* (fig. 492) with its numerous varieties.

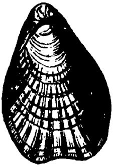
Among the brachiopoda, *Terebratula hastata* (fig. 493) deserves mention, not only for its wide range, but because it often retains the pattern of the original coloured stripes which ornamented the living shell. These coloured bands are also preserved in several lamellibranchiate bivalves, as in *Aviculopecten* (fig. 494), in which dark stripes alternate with a light ground. In some also of the spiral univalves, the pattern of the original painting is distinctly retained, as in *Pleurotomaria*

Fig. 492.



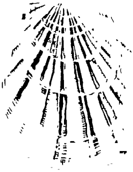
Spirifera glabra, Martin, sp. Carboniferous Limestone.

Fig. 493.



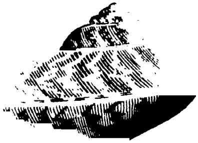
Terebratula hastata, Sow., with radiating bands of colour. Carboniferous Limestone. Derbyshire; Ireland; Russia; &c.

Fig. 494.



Aviculopecten sublobatus, Phill. Carboniferous Limestone. Derbyshire; Yorkshire.

Fig. 495.

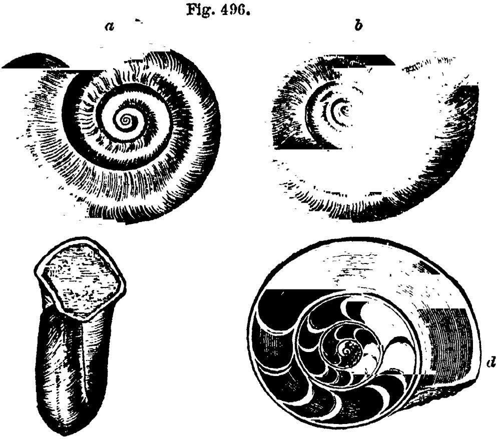


Pleurotomaria carinata, Sow. (*P. flammigera,* Phill.) Carboniferous Limestone. Derbyshire, &c.

(fig. 495), which displays wavy blotches, resembling the colouring in many recent Trochidæ.

Some few of the carboniferous mollusca, such as *Avicula,* *Nucula* (subgenus *Ctenodonta*), *Solemya*, and *Lithodomus*, belong no doubt to existing genera; but the majority, though often referred to as living types, such as *Isocardia*, *Turritella*, and *Buccinum*, belong really to forms which appear to have become extinct at the close of the Palæozoic epoch. *Euomphalus* is a characteristic univalve shell of this period. In the interior it is divided into chambers (fig. 496, *d*), the septa or partitions not being perforated as in foraminiferous shells, or in those having siphuncles, like the Nautilus. The animal appears to have retreated at different periods of its growth from the internal cavity previously formed, and to have closed all communication with it by a septum. The number of chambers is irregular, and they are generally wanting in the innermost whorl. The animal of the recent *Turritella communis* partitions off in like manner, as it advances in age, a part of its spire, forming a shelly septum.

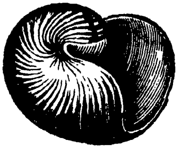
Fig. 496.



Euomphalus pentangulatus, Sowerby. Mountain Limestone.

a. Upper side. *b.* Lower or umbilical side. *c.* View, showing mouth, which is less pentagonal in older individuals. *d.* View of polished section, showing internal chambers.

Fig. 497.

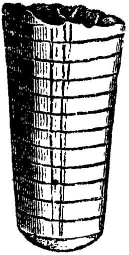


Bellerophon costatus, Sow. Mountain Limestone.

More than twenty species of the genus *Bellerophon* (see fig. 487), a shell like the living Argonaut without chambers, occur in the Mountain Limestone. The genus is not met with in strata of later date. It is most generally regarded as belonging to the pelagic Nucleobranchiata and the family Atlantidæ, partly allied to the Glass-Shell, *Carinaria*; by some, however, it is thought to be a simple form of Cephalopod.

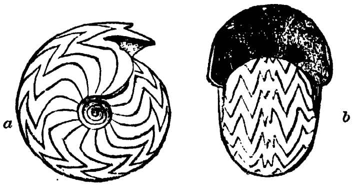
The carboniferous Cephalopoda do not depart so widely from the living type (the Nautilus) as do the more ancient Silurian representatives of the same order; yet they offer some remarkable forms. Among these is *Orthoceras*, a siphuncled and chambered shell, like a *Nautilus* uncoiled and straightened (fig. 498). Some species of this genus are several feet long.

Fig. 498.



Portion of *Orthoceras laterale*, Phillips. Mountain Limestone.

Fig. 499.



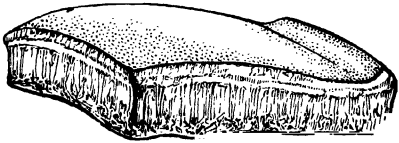
Goniatites crenistria, Phill.
Mountain Limestone.
N. America; Britain; Germany; &c.
a. Lateral view.
b. Front view, showing the mouth.

The *Goniatite* is another genus, nearly allied to the *Ammonite*, from which it differs in having the lobes of the septa free from lateral denticulations, or crenatures; so that the outline of these is angular, continuous, and uninterrupted. The species represented in fig. 499 is found in most localities, and presents the zigzag character of the septal lobes in great perfection. The dorsal position of the siphuncle, however, clearly distinguishes the Goniatite from the Nautilus, and proves it to have belonged to the Ammonitidæ, from which, indeed, some authors do not believe it to be generically distinct.

Fossil Fish.—The distribution of these is singularly partial; so much so, that the eminent palæontologist, M. de Koninck of Liége, once stated to me that, in making his extensive collection of the fossils of the Mountain Limestone of Belgium, he had found no more than four or five examples of the bones or teeth of fishes. Judging from Belgian data, he might have concluded that this class of vertebrata was of extreme rarity in the carboniferous seas; whereas the investigation of other countries has led to quite a different result. Thus, near Clifton, on the Avon, as well as at numerous places around the Bristol basin from the Mendip Hills to Tortworth, there is a celebrated 'bone-bed,' almost entirely made up of ichthyolites.

It occurs at the base of the Lower Limestone shales immediately resting upon the passage beds of the Old Red Sandstone. Similar bone-beds occur in the Carboniferous Limestone of Armagh, in Ireland, where they are made up chiefly of the teeth of Placoid fishes, nearly all of them rolled as if drifted from a distance. Some teeth are sharp and pointed, as in ordinary sharks, of which the genus *Cladodus* affords an illustration; but the majority, as in *Psammodus* and *Cochliodus*, are, like the teeth of the Cestracion of Port Jackson (see above, fig. 267, p. 280), massive palatal teeth fitted for grinding (see figs. 500, 501).

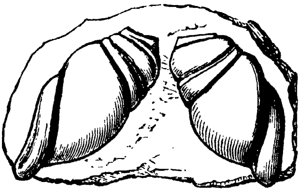
Fig. 500.



Psammodus porosus, Agass. Bone-bed, Mountain Limestone. Bristol; Armagh.

There are upwards of seventy other species of fossil fish known in the Mountain Limestone of the British Islands. The defensive fin-bones of these creatures are not unfrequent at Armagh and Bristol; those known as *Oracanthus*, *Ctenacanthus*, and *Onchus* are often of a very large size. Ganoid fish, such as *Holoptychius*, also occur; but these are far less numerous. The great *Megalichthys Hibberti* appears to range from the Upper Coal-measures to the lowest Carboniferous strata.

Fig. 501.



Cochliodus contortus, Agass. Bone-bed, Mountain Limestone. Bristol; Armagh.

Foraminifera.—In the upper part of the Mountain Limestone group in the S.W. of England, near Bristol, limestones having a distinct oolitic structure alternate with shales. In these rocks the nucleus of almost every minute spherule is seen, under the microscope, to consist of a small rhizopod or fora-

which is represented so fully at later epochs by the Nummulites and their numerous minute allies, appears in the Mountain Limestone to be restricted to a very few species, among which *Textularia*, *Nodosaria*, *Endothyra*, and *Fusulina* (fig. 502) have been recognised.

Fig. 502.

Fusulina cylindrica D'Orb. Magnified 3 diam. Mountain Limestone.

The first two genera are common to this and all the after periods; the third has been found in the Upper Silurian, but is not known above the Carboniferous strata; the fourth (fig. 502) is characteristic of the Mountain Limestone in the United States, Arctic America, Russia, and Asia Minor, but is also known in the Permian.

CHAPTER XXV.

DEVONIAN OR OLD RED SANDSTONE GROUP.

Classification of the Old Red Sandstone in Scotland and in Devonshire—Upper Old Red Sandstone in Scotland, with fish and plants—Middle Old Red Sandstone—Classification of the Ichthyolites of the Old Red, and their relation to living types—Lower Old Red Sandstone, with *Cephalapsis* and *Pterygotus*—Marine or Devonian type of Old Red Sandstone—Table of Devonian series—Upper Devonian rocks and fossils—Middle—Lower—Eifel Limestone of Germany—Devonian of Russia—Devonian Strata of the United States and Canada—Devonian Plants and Insects of Canada.

Classification of the two types of Old Red Sandstone.—We have seen that the Carboniferous strata are surmounted by the Permian and Trias, both originally included in England under the name 'New Red Sandstone,' from the prevailing red colour of the strata. Under the coal came other red sandstones and shales which were distinguished by the title of 'Old Red Sandstone.' Afterwards the name of 'Devonian' was given by Sir R. Murchison and Professor Sedgwick to marine fossiliferous strata which, in the South-west of England, occupy a similar position between the overlying coal and the underlying Silurian formations, the latter, however, not being exposed in North Devon.

It may be truly said that in the British Isles the rocks of this age present themselves in their mineral aspect, and even to some extent in their fossil contents, under two very different aspects ; the one as distinct from the other as are often lacustrine or fluviatile from marine strata. It has indeed been suggested that by far the greater part of the deposits belonging to the Old Red Sandstone are of freshwater origin. The character of the land plants, and of the fishes, and the fact that the only shell yet discovered belongs to the genus *Anodonta,* must be allowed to lend no small countenance to this opinion. In this case the difficulty of classification when the strata of this type are compared in different regions, even where they are contiguous, may arise partly from their having been formed in distinct hydrographical basins, or in the neighbourhood of the land in shallow parts of the sea into which large bodies of fresh water entered, and where no marine mollusca or corals could flourish. Under such geographical conditions the limited extent of some kinds of sediment as well as the absence of those marine forms by which we are able to identify or contrast marine formations, may be explained, while the great thickness of the rocks which might seem at first sight to require a corresponding depth of water can often be shown to have been due to the gradual sinking of the bottom of the estuary or sea in which the sediment was accumulated. Professor Ramsay, when speculating on this subject, has traced out the probable changes which marked the passage from the antecedent Silurian ocean to a continental condition at the time of the beginning of the Old Red Sandstone, when the sea was gradually converted first into a series of lagoons and finally into great freshwater lakes.

In Ireland and Scotland the upper division of the Old Red Sandstone lies unconformably upon the lower, and in South Wales the upper beds overlap the lower strata, 'indicating,' says Professor Ramsay, 'great disturbance and denudation,' but not presenting any insuperable difficulty as to the freshwater origin of the strata; for the explanation already given (p. 363) with regard to the Trias, of the manner in which overlapping strata might now be produced in the region of the Dead Sea, will apply equally to the Old Red formation. As regards the meagre fauna of the Old Red Sandstone, Professor Ramsay suggests that a parallel is to be found in the impoverished fauna of the Caspian Sea, which is now separated from the ocean and gradually growing salter by evaporation; but if by an increase of rainfall this inland sea were to become freshened, it would then exhibit a passage from marine to freshwater conditions very similar to that which marks the advent of the Old Red Sandstone.[1]

Another active cause of local variation in Scotland was the frequency of contemporaneous volcanic eruptions; some of the rocks derived from this source, as between the Grampians and the Tay, having formed islands in the sea, and having been converted into shingle and conglomerate, before the upper portions of the red shales and sandstones were superimposed.

A dearth of calcareous matter over wide areas is characteristic of the Old Red Sandstone. This is, no doubt, in great part due to the absence of shells and corals; but why should these be so generally wanting in all sedimentary rocks the colour of which is determined by the red oxide of iron? It cannot be said that any satisfactory conclusion has yet been arrived at on this subject. Some geologists are of opinion that the waters impregnated with this oxide were prejudicial to living beings; others that strata permeated with this oxide would not preserve such fossil remains. We have already referred (p. 363) to the recent deposits of oxide of iron in certain Swedish lakes, a geological examination of which might, perhaps, throw light on this subject.

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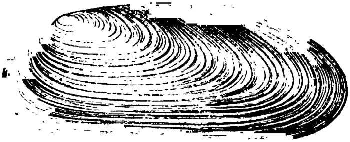
[1] Contemporary Review, July 1873, p. 200.

In regard to the two types, the Old Red Sandstone and the Devonian, I shall first treat of them separately, and then allude to the proofs of their having been to a great extent contemporaneous. That they constitute a series of rocks intermediate in date between the lowest Carboniferous and the uppermost Silurian is not disputed by the ablest geologists ; and it can no longer be contended that the Upper, Middle, and Lower Old Red Sandstone preceded in date the three divisions to which by aid of the marine shells the Devonian rocks have been referred, while, on the other hand, we have not yet data for enabling us to affirm to what extent the subdivisions of the one series may be the equivalents in time of those of the other.

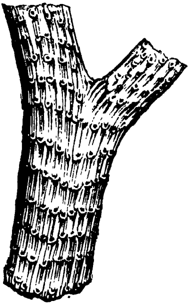
Fig. 503.



Anodonta Jukesii, Forbes.
Upper Devonian, Kiltorkan, Ireland.

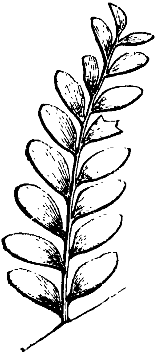
Upper Old Red Sandstone.—The highest beds of the series in Scotland, lying immediately below the coal in Fife, are composed of yellow sandstone well seen at Dura Den near Coupar, in Fife, where, although the strata contain no mollusca, fish have been found abundantly, and have been referred to the genera *Holoptychius*, *Pamphractus*, *Glyptopomus*, and many others. In the county of Kilkenny in Ireland, a similar yellow sandstone occurs containing fish of genera characteristic of the Scotch Old Red Sandstone, as for example *Coccosteus* (a form represented by many species in the Old Red Sandstone and by one only in the Carboniferous group) and *Glytolepis*, which is exclusively confined to the 'Old Red.' In the same Irish sandstone at Kiltorkan has been found an *Anodonta* or freshwater mussel, the only shell hitherto discovered in the Old Red Sandstone of the British Isles (see fig. 503). In the same beds are found the fern (fig. 505) and the *Lepidodendron*, (fig. 504), and twelve other species of plants, some of which, Professor Heer remarks, agree specifically with species from the Lower Carboniferous beds. This induces him to lean to the opinion, long ago advocated by Sir Richard Griffith, that the yellow sandstone, in spite of its fish remains, should be classed as Lower Carboniferous—an opinion which I am not yet prepared to adopt. Between the Mountain Limestone and the yellow sandstone in the south-west of Ireland there intervenes a formation no less than 5,000 feet thick, called the 'Carboniferous slate;' and at the base of this, in some places, are local deposits, such as the Coomhola Grits, which appear to be beds of passage between the Carboniferous and Old Red Sandstone groups.

Fig. 504.



Bifurcating branch of *Lepidodendron Griffithsii*, Brong. Upper Devonian, Kilkenny.

Fig. 505.

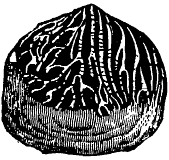


Palæopteris Hibernica, Schimp. (*Cyclopteris Hibernica*, Ed. Forbes.) (*Adiantites*, Goep.) Upper Devonian, Kilkenny.

It is a remarkable result of the recent examination of the fossil flora of Bear Island, lat. 74° 30′ N., that Professor Heer has described as occurring in that part of the Arctic region (nearly twenty-six degrees to the north of the Irish locality) a flora agreeing in several of its species with that of the yellow sandstones of Ireland. This Bear Island flora is believed by Professor Heer to comprise species of plants some of which ascend even to the higher stages of the European Carboniferous formation, or as high as the Mountain Limestone and Millstone Grit. Palæontologists have long maintained that the same species which have a wide range in space are also the most persistent in time, which may prepare us to find that some plants having a vast geographical range may also have endured from the period of the Upper Devonian to that of the Millstone Grit.

Outliers of the Upper 'Old Red' occur unconformably on older members of the group, and the formation represented at Whiteness near Arbroath (*a*, fig. 55, p. 51) may probably be one of these outliers, though the want of organic remains renders this uncertain. It is not improbable that the beds given in this section as Nos. 1, 2, and 3, may all belong to the early part of the period of the Upper Old Red, as some scales of *Holoptychius nobillissimus* have been found scattered through the beds, No. 2, in Strathmore. Another nearly allied *Holoptychius* occurs in Dura Den. A figure of this genus is annexed (fig. 507), and also one of its scales (fig. 506), as these last are often the only parts met with; being scattered in Forfarshire through red-coloured shales and sandstones, as are scales of a large species of the same genus in a corresponding matrix in Herefordshire and Somersetshire.[1] The number of fish obtained from the British Upper Old Red Sandstone amounts to fifteen species referred to eleven genera.

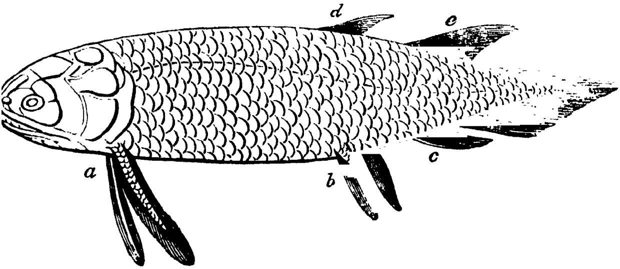
Fig. 506.



Scale of *Holoptychius nobilissimus*, Ag. Clashbinnie. ½ nat. size.

Sir R. Murchison groups with this upper division of the Old Red of Scotland certain light-red and yellow sandstones and grits which occur in the northernmost part of the mainland and extend also into the Orkney and Shetland Islands. They contain Calamites and other plants which agree generically with Carboniferous forms.

Fig. 507.



Holoptychius. As restored by Prof. Huxley.

a. The fringed pectoral fins. *c.* Anal fin.
b. The fringed ventral fins. *d, e.* Dorsal fins.

Middle Old Red Sandstone.—In the northern part of Scotland there occurs a great series of bituminous schists and flagstones, to the fossil fish of which attention was first called by the late Hugh Miller. They were afterwards described by Agassiz, and the rocks containing them were examined by Sir R. Murchison and Professor Sedgwick, in Caithness, Cromarty, Moray, Nairn, Gamrie in Banff, and the Orkneys and Shetlands, in which great numbers of fossil fish have been found. These were at first supposed to be the oldest known vertebrate animals, as in Cromarty the beds in which they occur seem to form the base of the Old Red system resting almost immediately on the crystalline or metamorphic rocks. But in fact these fish-bearing beds, when they are traced from north to south, or to the central parts of Scotland, thin out, so that their relative age to the Lower Old Red Sandstone, presently to be mentioned, was not at first detected, the two formations not appearing in superposition in the same district. In Caithness, however, many hundred feet below the fish-zone of the middle division, remains of *Pteraspis* were found by Mr. Peach in 1861. This genus has never yet been found in either of the two higher divisions of the Old Red Sandstone, and confirms Sir R. Murchison's previous suspicion that the rocks in which it occurs belong to the Lower 'Old Red,' or agree in age with the Arbroath paving-stone.[1]

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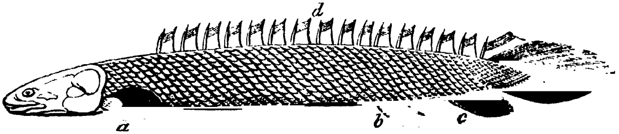
[1] Siluria, 4th ed. p. 265.

Fossil fish of the Middle Old Red Sandstone.—The Devonian fish were referred by Agassiz to two of his great orders, namely, the Placoids and Ganoids. Of the first of these, which in the Recent period comprise the shark, the dog-fish, and the ray, no entire skeletons are preserved; but fin-spines, called Ichthyodorulites, and teeth occur. On such remains the genera *Onchus*, *Odontacanthus*, and *Ctenodus*, a supposed cestraciont, and some others, have been established.

By far the greater number of the Old Red Sandstone fishes belong to a sub-order of Ganoids instituted by Huxley in 1861, and for which he has proposed the name of *Crossopterygidæ*,[2] or the fringe-finned, in consideration of the peculiar manner in which the fin-rays of the paired fins are arranged so as to form a fringe round a central lobe, as in the *Polypterus* (see *a*, fig. 508), a genus of which there are several species now inhabiting the Nile and other African rivers. The reader will at once recognise in *Osteolepis* (fig. 509) one of the common fishes of

Fig. 508.



Polypterus. See Agassiz, 'Recherches sur les Poissons Fossiles.' Living in the Nile and other African rivers.

a. One of the fringed pectoral fins. *c*. Anal fin.
b. One of the ventral fins. *d*. Dorsal fin, or row of finlets.

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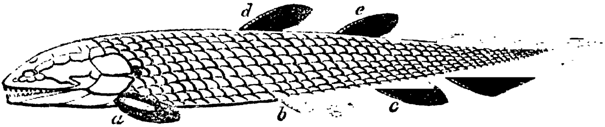
[1] Siluria, 4th ed. p. 258.

[2] Abridged from κροσσωτος, crossotos, a fringe, and πτερυξ, pteryx, a fin.

the Old Red Sandstone, many points of analogy with *Polypterus*. They not only agree in the structure of the fin, as first pointed out by Huxley, but also in the position of the pectoral, ventral, and anal fins, and in having an elongated body and rhomboidal scales. On the other hand, the tail is more symmetrical in the recent fish, which has also an apparatus of dorsal finlets of a very abnormal character, both as to number and structure. As to the dorsals of *Osteolepis*, they are regular in structure and position, having nothing remarkable about them, except that there are two, which is comparatively unusual in living fish.

Fig. 509.



Restoration of *Osteolepis*. Pander. Old Red Sandstone, or Devonian.
a. One of the fringed pectoral fins. *c*. Anal fins.
b. One of the ventral fins. *d*, *e*. Dorsal fins.

Among the 'fringe-finned' Ganoids we find some with rhomboidal scales, such as *Osteolepis*, above figured; others with cycloidal scales, as *Holoptychius*, before-mentioned (see fig. 507, p. 438). In the genera *Dipterus* and *Diplopterus*, as Hugh Miller pointed out, and in several other of the fringe-finned genera, as in *Gyroptychius* and *Glyptolepis*, the two dorsals are placed far backwards, or directly over the ventral and anal fins. The *Asterolepis* (one of the Placodermata) was a ganoid fish of large dimensions. *A. Asmusii*, Eichwald, a species characteristic of the Old Red Sandstone (Devonian) of Russia, as well as of the Middle and Upper division of the same rocks in Scotland, attained, according to Hugh Miller,[1] the length of between twenty and thirty feet. The *Asterolepi* were partly clothed with strong bony armour, embossed with starlike tubercles. The *Asterolepis* occurs also in the Devonian rocks of North America.

If we except the Placoids already alluded to, and a few other families of doubtful affinities, all the Old Red Sandstone fishes are Ganoids, an order so named by Agassiz from the shining outer surface of their scales; but Prof. Huxley has also called our attention to the fact, that, while a few of the primary and the great majority of the secondary Ganoids resemble the living bony pike, *Lepidosteus*, or the *Amia*, genera now found in North

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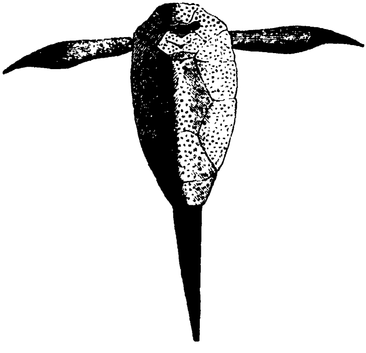
[1] Footprints of Creation, p. 103.

American rivers, and one of them, *Lepidosteus*, extending as far south as Guatemala, the Crossopterygii, or fringe-finned Ichthyolites, of the Old Red are closely related to the African *Polypterus*, which is represented by five or six species now inhabiting the Nile and the rivers of Senegal. These North American and African Ganoids are quite exceptional in the living creation ; they were until lately considered to be entirely confined to the northern hemisphere, but in 1870 another genus of the Crossopterygii, *Ceratodus Forsteri*, was found living in the rivers of Queensland, Australia ;[1] out of about 9,000 living species of fish known to M. Günther, and of which more than 6,000 are now preserved in the British Museum, they probably constitute no more than nine.

If many circumstances favour the theory of the freshwater origin of the Old Red Sandstone, this view of its nature is not a little confirmed by our finding that it is in Lake Superior and the other inland Canadian freshwater seas, and in the Missisipi and African rivers, that we at present find those fish which have the nearest affinity to the fossil forms of this ancient formation.

Fig. 510.



Pterichthys, Agassiz ; Upper side, showing mouth ; as restored by H. Miller.

Among the anomalous forms of Old Red fishes not referable to Huxley's Crossopterygii is the *Pterichthys*, of which five species have been found in the middle division of the Old Red of Scotland. Some writers have compared their shelly covering to that of Crustaceans, with which, however, they have no real affinity. The wing-like appendages, whence the genus is named, were first supposed by Hugh Miller to be paddles, like those of the turtle ; and there can now be no doubt that they do really correspond with the pectoral fins.

The number of species of fish already obtained from the middle division of the Old Red Sandstone in Great Britain is about 70, and the principal genera, besides *Osteolepis*, and *Pte-*

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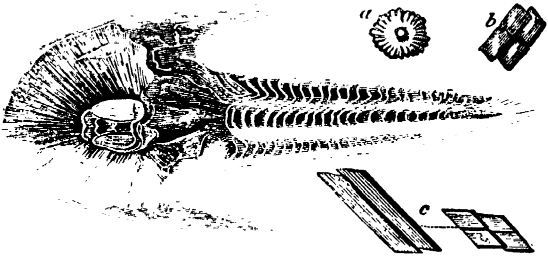
[1] Günther on Ceratodus, Phil. Trans. Royal Soc., part 2, 1871, p. 511.

richthys, already mentioned, are *Glyptolepis*, *Diplacanthus*, *Dendrodus*, *Coccosteus*, *Cheiracanthus*, and *Acanthoides*.

Lower Old Red Sandstone.—The third or lowest division south of the Grampians consists of grey paving-stone and roofing-slate, with associated red and grey shales; these strata underlie a dense mass of conglomerate. In these grey beds several remarkable fish have been found of the genus named by Agassiz *Cephalaspis*, or 'buckler-headed,' from the extraordinary shield which covers the head (see fig. 511), and which has often been mistaken for that of a trilobite, such as *Asaphus*. A species of *Pteraspis*, of the same family, has also been found by the Rev. Hugh Mitchell in beds of corresponding age in Perthshire; and Mr. Powrie enumerates no less than five genera of the family Acanthodidæ, the spines, scales, and other remains of which have been detected in the grey flaggy sandstones.[1]

Fig. 511.

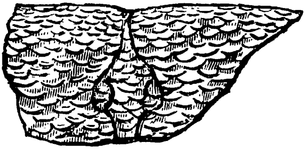


Cephalaspis Lyellii, Agass. Length 6¾ inches.
From a specimen in my collection found at Glammiss, in Forfarshire.
(See other figures, Agassiz, vol. ii. tab. 1 *a* and 1 *b*.)

a. One of the peculiar scales with which the head is covered when perfect. These scales are generally removed, as in the specimen above figured.

b. *c*. Scales from different parts of the body and tail.

Fig. 512.



Pterygotus anglicus, Agassiz.
Middle portion of the back of the head called the 'Seraphim.'

In the same formation at Carmylie, in Forfarshire, commonly known as the Arbroath paving-stone, fragments of a huge crustacean have been met with from time to time. They are called by the Scotch quarrymen the 'Seraphim,' from the wing-like form and feather-like ornament of the thoracic appendage, the part most usually met with. Agassiz, having previously referred some of these fragments to the class of fishes, was the first to recognise their crustacean character, and, although at the time unable correctly to determine the true relation of the several parts, he figured the portions on which he founded his opinion, in the first plate of his 'Poissons Fossiles du Vieux Grès Rouge.'

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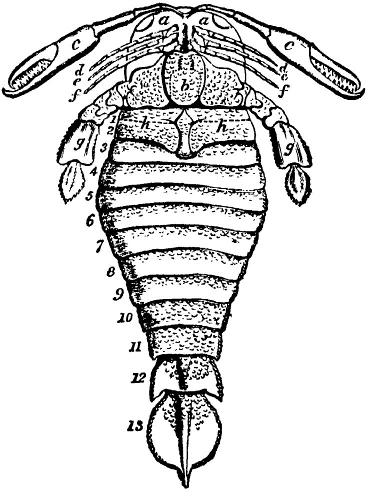
[1] Powrie, Geol. Quart. Journ., vol. xx. p. 417.

A restoration in correct proportion to the size of the fragments of *P. Anglicus* (fig. 513), from the Lower Old Red Sandstone of Perthshire and Forfarshire, would give us a creature measuring from 5 to 6 feet in length, and more than 1 foot across.

Fig. 513.



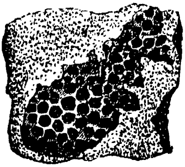
Pterygotus anglicus. Ag., Forfarshire. Ventral aspect. Restored by H. Woodward, F.R.S.

- *a.* Carapace, showing the large sessile eyes at the anterior angles.
- *b.* The *metastoma* or post-oral plate (serving the office of a lower lip).
- *c, c.* Chelate appendages (*antennules*).
- *d.* First pair of simple palpi (*antennæ*).
- *e.* Second pair of simple palpi (*mandibles*).
- *f.* Third pair of simple palpi (first *maxillæ*).
- *g.* Pair of swimming feet with their broad basal joints, whose serrated edges serve the office of *maxillæ*.
- *h.* Thoracic plate covering the first two thoracic segments, which are indicated by the figures 1, 2, and a dotted line.
- 1–6. Thoracic segments.
- 7–12. Abdominal segments.
- 13. Telson, or tail-plate.

The largest crustaceans living at the present day are the *Inachus Kæmpferi*, of De Haan, from Japan (a brachyurous or short-tailed crab), chiefly remarkable for the extraordinary length of its limbs ; the fore-arm measuring 4 feet in length, and the others in proportion, so that it covers about 25 square feet of ground ; and the *Limulus Moluccanus*, the great King Crab of China and the eastern seas, which, when adult, measures 1½ foot across its carapace, and is 3 feet in length.

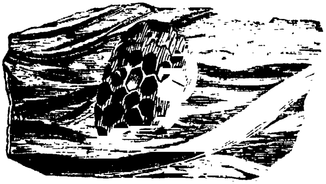
Besides some species of *Pterygotus*, several of the allied genus *Eurypterus* occur in the Lower Old Red Sandstone, and with them the remains of grass-like plants so abundant in Forfarshire and Kincardineshire as to be useful to the geologist by enabling him to identify the inferior strata at distant points. Some botanists have suggested that these plants may be of the family *Fluviales*, and of freshwater genera. They are accompanied by fossils, called 'berries' by the quarrymen, which they compared to a compressed blackberry (see figs. 514, 515), and which were called 'Parka' by Dr. Fleming. They are now considered by Mr. Powrie to be the eggs of crustaceans ; which is highly probable, for they have not only been found with *Pterygotus Anglicus* in Forfarshire and Perthshire, but also in the Upper Silurian strata of England in which species of the same genus, Pterygotus, occur.

Fig. 514.



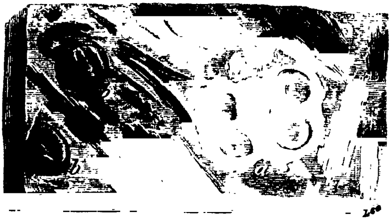
Parka decipiens, Fleming.
In sandstone of lower beds of Old Red, Ley's Mill, Forfarshire.

Fig. 515.



Parka decipiens, Fleming.
In shale of Lower Old Red, Park Hill, Fife.

Fig. 516.



Old Red Sandstone Shale of Forfarshire. With impression of plants and ova of Crustaceans.

a. Two pair of ova? resembling those of large Salamanders or Tritons—on the same leaf.
b, b Detached ova.

The grandest exhibitions, says Sir R. Murchison, of the Old Red Sandstone in England and Wales appear in the escarpments of the Black Mountains and in the Fans of Brecon and Carmarthen, the one 2,862, and the other 2,590 feet above the sea. The mass of red and brown sandstone in these mountains is estimated at not less than 10,000 feet, clearly intercalated between the Carboniferous and Silurian strata. No shells or corals have ever been found in the whole series, not even where the beds are calcareous, forming irregular courses of concretionary lumps called 'cornstones,' which may be described as mottled red and green earthy limestones. The fishes of this lowest English Old Red are *Cephalaspis* and *Pteraspis*, specifically different from species of the same genera which occur in the uppermost Ludlow or Silurian tilestones. Crustaceans also of the genus *Eurypterus* are met with.

Marine or Devonian type.—We may now speak of the marine type of the British strata intermediate between the Carboniferous and Silurian, in treating of which we shall find it much more easy to identify the Upper, Middle, and Lower divisions with strata of the same age in other countries. It was not until the year 1836 that Sir R. Murchison and Professor Sedgwick discovered that the culmiferous or anthracitic shales and sandstones of North Devon, several thousand feet thick, belonged to the coal; and that the beds below them, which are of still greater thickness, and which, like the carboniferous strata, had been confounded under the general name 'greywacke,' occupied a geological position corresponding to that of the Old Red Sandstone already described. In this reform they were aided by a suggestion of Mr. Lonsdale, who, after studying the Devonshire fossils, perceived that they belonged to a peculiar palæontological type of intermediate character between the Carboniferous and Silurian.

It is in the north of Devon that these formations may best be studied, where they have been divided into an Upper, Middle, and Lower Group, and where, although much contorted and folded, they have for the most part escaped being altered by intrusive trap-rocks and by granite, which in Dartmoor and the more southern parts of the same county have often reduced them to a crystalline or metamorphic state.

The following table exhibits the sequence of the strata or subdivisions as seen both on the sea-coast of the British Channel and in the interior of Devon. It will be seen that in all main points it agrees with the table drawn up in 1864 for the sixth edition of my 'Elements.' Mr. Etheridge[1] has since published an excellent account of the different subdivisions of the rocks and their fossils, and has also pointed out their relation to the corresponding marine strata of the Continent. The slight modifications introduced in my table since 1864 are the result of a tour made in 1870 in company with Mr. T. M'K. Hughes, when we had the advantage of Mr. Etheridge's memoir as our guide.

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[1] Quart. Geol. Journ. vol. xxiii. 1867.

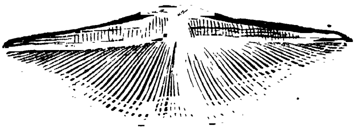
DEVONIAN SERIES IN NORTH DEVON.

Upper Devonian or Pilton Group.	(*a.*) Sandy slates and schists with fossils, 36 species out of 110 common to the Carboniferous group (Pilton, Barnstaple, &c.), resting on soft schists in which fossils are very abundant (Croyde, &c.), and which pass down into
	(*b.*) Yellow, brown, and red sandstone, with land plants (*Cyclopteris*, &c.) and marine shells. One zone, characterised by the abundance of Cucullæa (Baggy Point, Marwood, Sloly, &c.), resting on hard grey and reddish sandstone and micaceous flags; no fossils yet foun (Dulverton, Pickwell, Down, &c.).
Middle Devonian or Ilfracombe Group.	(*a.*) Grey glossy slates of considerable thickness, bearing quartz veins; no fossils yet recorded from these beds (Morthœ, Lee Bay, &c.).
	(*b.*) Slates and schists, with irregular courses of limestone containing shells and corals like those of the Torbay and Plymouth Limestone (Combe Martin, Ilfracombe, &c.).
Lower Devonian or Lynton Group.	(*a.*) Hard, greenish, red, and purple sandstone (Hangman Hill, &c.).
	(*b.*) Soft slates with subordinate sandstones—fossils numerous at various horizons—Brachiopoda, Corals, Encrinites, &c. (Valley of Rocks, Lynmouth, &c.)

The place of the sandstones of the Foreland is not yet clearly made out, as they are cut off by a great fault and disturbance.

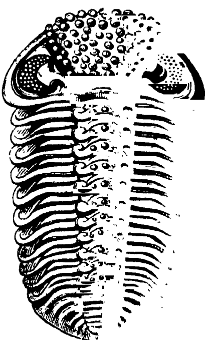
Upper Devonian rocks.—The slates and sandstones of Barnstaple (*a* and *b* of the preceding section) contain the shell *Spirifera disjuncta*, Sow. (*S. Verneuilii*, Murch.), (see fig. 517), which has a very wide range in Europe, Asia Minor, and even China; also *Stropthalosia caperata*, together with the large trilobite *Phacops latifrons*, Bronn. (see fig. 518), which is all but world-wide in its distribution. The fossils are numerous, and comprise about 150 species of mollusca, a fifth of which pass up into the overlying Carboniferous rocks. To this

Fig. 517.



Spirifera disjuncta, Sow. Syn. *Sp. Verneuilii*, Murch.
Upper Devonian, Boulogne.

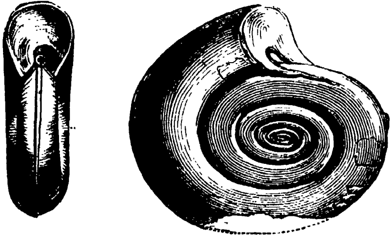
Fig. 518.



Phacops latifrons, Bronn.
Characteristic of the Devonian in Europe, Asia, and N. and S. America.

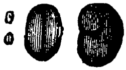
Upper Devonian belong a series of limestones and slates well developed at Petherwyn, in Cornwall, where they have yielded 75 species of fossils. The genus of Cephalopoda called *Clymenia* (fig. 519) is represented by no less than 11 species, and strata occupying the same position in Germany are called Clymenien-Kalk, or sometimes Cypridinen-Schiefer, on account of the number of minute bivalve shells of the crustacean called *Cypridina serrato-striata* (fig. 520), which is found in these beds, in the Rhenish provinces, the Harz, Saxony, and Silesia, as well as in Cornwall and Belgium.

Fig. 519.



Clymenia linearis, Münster.
Petherwyn, Cornwall; Elbersreuth, Bavaria.

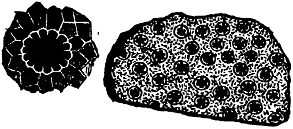
Fig. 520.



Cypridina serrato-striata,
Sandberger, Weilburg, &c.;
Cornwall; Nassau; Saxony;
Belgium.

Middle Devonian rocks.—We come next to the most typical portion of the Devonian system, including the great limestones of Plymouth and Torbay, as well as the slates and impure limestones of Ilfracombe, all replete with shells, trilobites, and corals. Of the corals 51 species are enumerated by Mr. Etheridge, none of which pass into the Carboniferous formation. Among the genera we find *Favosites*, *Heliolites*, and *Cyathophyllum*. The two former genera are very frequent in Silurian rocks: some few even of the species are said to be common to the Devonian and Silurian groups, as, for example, *Favosites cervicornis* (fig. 522), one of the commonest of all the Devonian corals. The *Cyathophyllum cæspitosum* (fig. 523) and *Heliolites porosa* (fig. 521) are species peculiar to this formation.

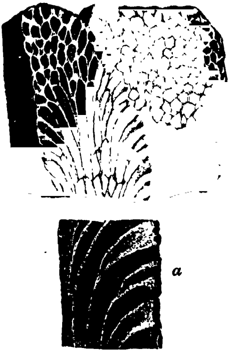
Fig. 521.



Heliolites porosa, Goldf., sp. (*Porites pyriformis*, Lonsd.).
a. One of the corallites magnified.
Middle Devonian, Torquay.
Plymouth, Eifel.

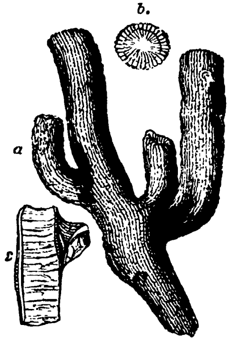
With the above are found no less than 11 genera of stone-lilies or crinoids, some of them, such as *Cupressocrinites*, distinct from any Carboniferous forms. The mollusca also are no less characteristic; of 68 species of Brachiopoda, 10 only are common to the Carboniferous series. The *Stringocephalus* *Burtini* (fig. 524) and *Uncites Gryphus* (fig. 525) may be mentioned as exclusively Middle Devonian genera, and extremely characteristic of the same division in Belgium. The *Stringocephalus* is also so abundant in the Middle Devonian of the banks of the Rhine as to have suggested the name of Stringocephalus Limestone. The only two species of Brachiopoda common to the Silurian and Devonian formations are *Atrypa reticularis* (fig. 541, p. 459), which seems to have been a cosmopolite species, and *Strophomena rhomboidalis*.

Fig. 522.



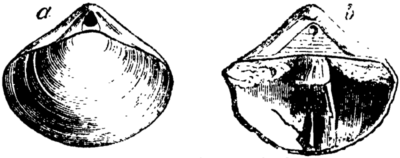
Favosites cervicornis, Blainv. S. Devon, from a polished specimen.
a. Portion of the same magnified, to show the pores.

Fig. 523.



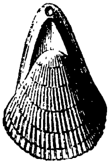
a. Cyathophyllum cæspitosum, Goldf.; Plymouth and Ilfracombe.
b. A terminal star.
c. Vertical section, exhibiting transverse plates, and part of another branch.

Fig. 524.



Stringocephalus Burtini, Def.
a. Valves united. *b.* Interior of ventral or large valve, showing thick partition and portion of a large process which projects from the dorsal valve across the shell.

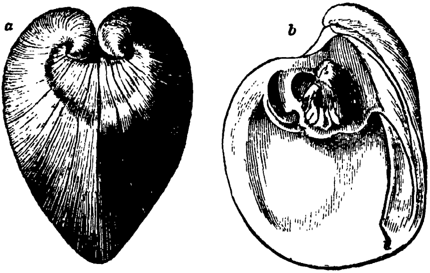
Fig. 525.



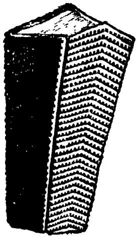
Uncites Gryphus, Def.
Middle Devonian.
S. Devon and the Continent.

Among the peculiar lamellibranchiate bivalves common to the Plymouth limestone of Devonshire and the Continent, we find the *Megalodon* (fig. 526). There are also 12 genera of Gasteropods which have yielded 36 species, 4 of which pass to the Carboniferous group, namely *Machrocheilus*, *Acroculia*, *Euomphalus*, and *Murchisonia*. Pteropods occur, such as *Conularia* (fig. 527), and the Cephalopods, *Cyrtoceras*, *Gyroceras*, *Orthoceras*, and others, nearly all of genera distinct from those prevailing in the Upper Devonian Limestone, or Clymenien-Kalk of the Germans already mentioned (p. 447). Although but few species of Trilobites occur, the characteristic *Bronteus flabellifer* (fig. 528) is far from rare, and all collectors are familiar with its fan-like tail. In this same group called, as before stated, the Stringocephalus or Eifel Limestone in Germany, several fish remains have been detected, and among others the remarkable genus *Coccosteus*

Fig. 526.

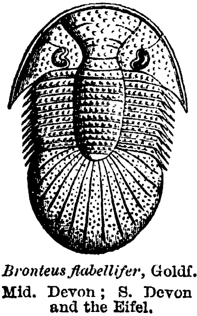


Megalodon cucullatus, Sow. Eifel; also Bradley, S. Devon.
a. The valves united.
b. Interior of valve, showing the large cardinal tooth.



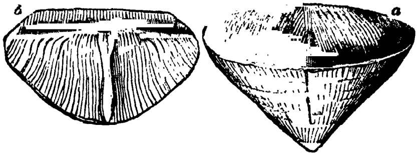
Conularia ornata, D'Arch. and De Vern. (Geol. Trans., Sec. Ser., vol. vi. Pl. 29.) Refrath, near Cologne.

Fig. 528.



Bronteus flabellifer, Goldf. Mid. Devon; S. Devon; and the Eifel.

Fig. 529.



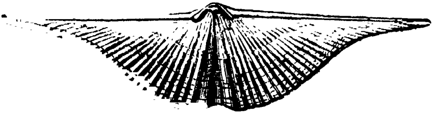
Calceola sandalina, Lam. Eifel; also South Devon.
a. Ventral valve.
b. Inner side of dorsal valve.

covered with its tuberculated bony armour; and these ichthyolites serve, as Sir R. Murchison observes ('Siluria', p. 362), to identify this middle marine Devonian with the Old Red Sandstone of Britain and Russia.

Beneath the Eifel Limestone (the great central and typical member of the 'Devonian' on the Continent) lie certain schists called by German writers 'Calceola-schiefer,' because they contain in abundance a fossil body of very curious structure, *Calceola sandalina* (fig. 529), which has been usually considered a Brachiopod, but which some naturalists have lately referred to a Goniophyllum, supposing it to be an abnormal form of the order *Zoantharia rugosa* (see fig. 482, p. 426), differing from all other corals in being furnished with a strong operculum. This is by no means a rare fossil in the slaty limestone of South Devon, and, like the Eifel form, is confined to the middle group of this country.

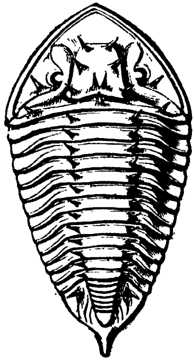
Lower Devonian rocks.—A great series of sandstones and glossy slates, with Crinoids, Brachiopods, and some corals and polyzoa, occurring on the coast at Lynmouth and the neighbourhood, and called the Lynton Group (see table, p. 446), form the lowest member of the Devonian in North Devon. Among the 18 species of all classes enumerated by Mr. Etheridge, two-thirds are common to the Middle Devonian; but only one, the ubiquitous *Atrypa reticularis*, can with certainty be identified with Silurian species. Among the characteristic forms are *Alveolites suborbicularis*, also common to this formation in the Rhine, and *Orthis arcuata*, very widely spread in the North Devon localities. But we may expect a large addition to the number of fossils whenever these strata shall have been carefully searched. The spirifer-sandstone of Sandberger, as exhibited in the rocks bordering the Rhine between Coblentz and Caub,

Fig. 530.



Spirifera mucronata, Hall. Devonian of Pennsylvania.

Fig. 531.



Homalonotus armatus, Burmeister. Lower Devonian, Daun, in the Eifel; and S. Devon.

Obs. The two rows of spines down the body give an appearance of more distinct trilobation than really occurs in this or most other species of the genus.

Devonian of Russia.—The Devonian strata of Russia extend, according to Sir R. Murchison, over a region more spacious than the British Isles ; and it is remarkable that, where they consist of sandstone like the 'Old Red' of Scotland and Central England, they are tenanted by fossil fishes often of the same species and still oftener of the same genera as the British, whereas when they consist of limestone they contain shells similar to those of Devonshire, thus confirming, as Sir Roderick has pointed out, the contemporaneous origin which had been previously assigned to formations exhibiting two very distinct mineral types in different parts of Britain.[1] The calcareous and the arenaceous rocks of Russia above alluded to alternate in such a manner as to leave no doubt of their having been deposited in different parts of the same great period.

Devonian strata in the United States and Canada.—Between the Carboniferous and Silurian strata there intervenes, in the United States and Canada, a great series of formations referable to the Devonian group, comprising some strata of marine origin abounding in shells and corals, and others of shallow water and littoral origin in which terrestrial plants abound. The fossils, both of the deep and shallow water strata, are very analogous to those of Europe, the species being in some cases the same. In Eastern Canada Sir W. Logan has pointed out that in the peninsula of Gaspé, south of the estuary of St. Lawrence, a mass of sandstone, conglomerate, and shale referable to this period occurs, rich in vegetable remains together with some fish-spines. Far down in the sandstones of Gaspé Dr. Dawson found in 1869 an entire specimen of the genus *Cephalaspis*, a form so characteristic, as we have already seen, of the Scotch Lower Old Red Sandstone. Some of the sandstones are ripple-marked ; and towards the upper part of the whole series a thin seam of coal has been observed, measuring, together with some associated carbonaceous shale, about three inches in thickness. It rests on an underclay in which are the roots of Psilophyton (see fig. 532). At many other levels rootlets of this same plant have been shown by Principal

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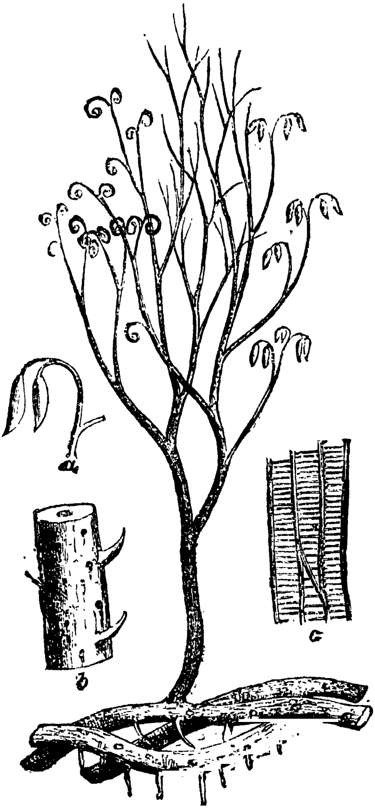
[1] Murchison's Siluria, p. 329.

Dawson to penetrate the clays, and to play the same part as do the rootlets of Stigmaria in the coal formation.

Fig. 532.



Psilophyton princeps, Dawson, Geol. Quart. Journ., vol. xv. 1863; and Canada Survey, 1863. Species characteristic of the whole Devonian series in North America.

a. Fruit; natural size. *b.* Stem; natural size. *c.* Scalariform tissue of the axis, highly magnified.

We had already learnt from the works of Gœppert, Unger, and Bronn that the European plants of the Devonian epoch resemble generically, with few exceptions, those already known as Carboniferous; and Dr. Dawson, in 1859, enumerated 32 genera and 69 species which he had then obtained from the State of New York and Canada. A perusal of his catalogue,[1] comprising *Coniferæ*, *Sigillariæ*, *Calamites*, *Asterophyllites*, *Lepidodendra*, and ferns of the genera *Cyclopteris*, *Neuropteris*, *Sphenopteris*, and others, together with fruits, such as *Cardiocarpum* and *Trigonocarpum*, might dispose geologists to believe that they were presented with a list of Carboniferous fossils, the difference of the species from those of the coal-measures, and even a slight admixture of genera unknown in Europe, being naturally ascribed to geographical distribution and the distance of the New from the Old World. But fortunately the coal formation is fully developed on the other side of the Atlantic, and is singularly like that of Europe, both lithologically and in the species of its fossil plants. There is also the most unequivocal evidence of relative age afforded by superposition, for the Devonian strata in the United States are seen to crop out from beneath the carboniferous on the borders of Pennsylvania and New York, where both formations are of great thickness.

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[1] Geol. Quart. Journ., vol. xv. p. 447. 1859; also vol. xviii. p. 296. 1862.

The number of American Devonian plants has now been raised by Dr. Dawson to 120, to which we may add about 80 from the European flora of the same age, so that already the vegetation of this period is beginning to be nearly half as rich as that of the coal-measures which have been studied for so much longer a time and over so much wider an area. The Psilophyton above alluded to is believed by Dr. Dawson to be a lycopodiaceous plant, branching dichotomously (see *P. princeps* (fig. 532), with stems springing from a rhizome, which last has circular areoles, much resembling those of Stigmaria, and like it sending forth cylindrical rootlets. The extreme points of some of the branchlets are rolled up so as to resemble the croziers or circinate vernation of ferns ; the leaves or bracts, *a*, supposed to belong to the same plant, are described by Dawson as having enclosed the fructification. The remains of *Psilophyton princeps* have been traced through all the members of the Devonian series in America, and Dr. Dawson has lately recognised it in specimens of Old Red Sandstone from the north of Scotland.

The monotonous character of the Carboniferous flora might be explained by imagining that we have only the vegetation handed down to us of one set of stations, consisting of wide swampy flats. But Dr. Dawson supposes that the geographical conditions under which the Devonian plants grew were more varied, and had more of an upland character. If so, the limitation of this more ancient flora represented by so many genera and species to the gymnospermous and cryptogamous orders, and the absence or extreme rarity of plants of higher grade, lead us naturally to speculate on the theory of progressive development, however difficult it may be to avail ourselves of this explanation.

Devonian insects of Canada.—The earliest known insects were brought to light in 1865 in the Devonian strata of St. John's, New Brunswick, and are referred by Mr. Scudder to four species of *Neuroptera*. One of them is a gigantic Ephemera, and measured five inches in expanse of wing.

Like many other ancient animals, says Dr. Dawson, they show a remarkable union of characters now found in distinct orders of insects, or constitute what have been named 'synthetic types.' Of this kind is a stridulating or musical apparatus like that of the cricket in an insect otherwise allied to the *Neuroptera.* This structure, as Dr. Dawson observes if rightly interpreted by Mr. Scudder, introduces us to the sounds of the Devonian woods, bringing before our imagination the trill and hum of insect life that enlivened the solitudes of these strange old forests.

CHAPTER XXVI.

SILURIAN GROUP.

Classification of the Silurian rocks—Ludlow formation and fossils—Bone-bed of the Upper Ludlow—Lower Ludlow shales with *Pentamerus*—Oldest known remains of fossil fish—Table of the progressive discovery of vertebrata in older rocks—Wenlock formation, corals, cystideans, and trilobites—Llandovery group or beds of passage—Lower Silurian rocks—Caradoc and Bala Beds—Brachiopoda—Trilobites—Cystideæ—Graptolites—Llandeilo Flags—Arenig or Stiper-stones group—Foreign Silurian equivalents in Europe—Barrande's Silurian fauna—Silurian strata of the United States—Canadian equivalents—Amount of specific agreement of fossils with those of Europe.

Classification of the Silurian rocks.—We come next in descending order to that division of Primary or Palæozoic rocks which immediately underlie the Devonian group of Old Red Sandstone. For these strata Sir Roderick Murchison first proposed the name of Silurian when he had studied and classified them in that part of Wales and some of the contiguous counties of England which once constituted the kingdom of the *Silures*, a tribe of ancient Britons. The following table will explain the two principal divisions, Upper and Lower, of the Silurian rocks, and the minor subdivisions usually adopted, comprehending all the strata originally embraced in the Silurian system by Sir Roderick Murchison. The formations below the Arenig or Stiper-stones group are treated of in the next chapter, when the Cambrian group is described.

UPPER SILURIAN ROCKS.

	Thickness in feet
1. LUDLOW FORMATION:	
a. Upper Ludlow beds	780
b. Lower Ludlow beds	1,050
2. WENLOCK FORMATION:	
a. Wenlock limestone and shale	above
b. Woolhope limestone and shale, and Denbighshire grits	4,000
3. LLANDOVERY FORMATION (Beds of passage between Upper and Lower Silurian):	
a. Upper Llandovery (May Hill beds)	800
b. Lower Llandovery	600—1,000

LOWER SILURIAN ROCKS.	Thickness in feet
1. Bala and Caradoc Beds, including volcanic rocks	12,000
2. Llandeilo Flags, including volcanic rocks	4,500
3. Arenig or Stiper-stones Group, including volcanic rocks	above 10,000

UPPER SILURIAN ROCKS.

1. Ludlow Formation.—This member of the Upper Silurian group, as will be seen by the above table, is of great thickness, and subdivided into two parts—the Upper Ludlow and the Lower Ludlow. Each of these may be distinguished near the town of Ludlow, and at other places in Shropshire and Herefordshire, by peculiar organic remains; but out of more than 500 species found in the Ludlow formation as a whole, not more than five species per cent. are common to the overlying Devonian. The student may refer to the excellent tables given in the last edition of Sir R. Murchison's 'Siluria' for a list of the organic remains of all classes distributed through the different subdivisions of the Upper and Lower Silurian.

a. **Upper Ludlow:** *Downton sandstone.*—At the top of this subdivision there occur beds of fine-grained yellowish sandstone and hard reddish grits which were formerly referred by Sir R. Murchison to the Old Red Sandstone, under the name of 'Tilestones.' In mineral character this group forms a transition from the Silurian to the Old Red Sandstone, the strata of both being conformable; but it is now ascertained that the fossils agree in great part specifically, and in general character entirely, with those of the underlying Upper Ludlow rocks. Among these are *Orthoceras bullatum*, *Platyschisma helicites*, *Bellerophon trilobatus*, *Chonetes lata*, &c., with numerous defences of fishes.

These beds, therefore, now generally called the 'Downton Sandstone,' are classed as the newest member of the Upper Silurian. They are well seen at Downton Castle, near Ludlow, where they are quarried for building, and at Kington in Herefordshire. In the latter place, as well as at Ludlow, crustaceans of the genera Pterygotus (for genus see fig. 513, p. 443) and Eurypterus are met with.

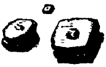
Bone-bed of the Upper Ludlow.—At the base of the Downton sandstones there occurs a bone-bed which deserves especial notice as affording the most ancient example of fossil fish occurring in any considerable quantity. It usually consists of one or two thin layers of brown bony fragments near the junction of the Old Red Sandstone and the Ludlow rocks, and was first observed by Sir R. Murchison near the town of Ludlow, where it is three or four inches thick. It has since been traced to a distance of 45 miles from that point into Gloucestershire and other counties, and is commonly not more than an inch thick, but varies to nearly a foot. Near Ludlow two bone-beds are observable, with 14 feet of intervening strata full of Upper Ludlow fossils.[1] Immediately above the upper fish-bed numerous small globular bodies have been found, which were determined by Dr. Hooker to be the sporangia of a cryptogamic land-plant, *Pachytheca sphærica*, probably lycopodiaceous.

Most of the fish remains have been referred by Agassiz to his placoid order, some of them to the genus Onchus, to which the spine (fig. 533) may be referred. The minute scales (fig. 534) may also belong to a placoid fish. It has been suggested, however, that Onchus may be one of those Acanthodian fish, referred by Agassiz to his Ganoid order, which are so characteristic of the base of the Old Red Sandstone in Forfarshire, although the species of the Old Red are all different from these of the Silurian beds now under consideration. Associated with these fish defences or Ichthyodorulites, and closely resembling them, are numerous prongs or tail spines of large phyllopod crustaceans which have been and are still frequently mistaken for the dorsal spines of fish. The jaw and teeth of another predaceous genus, *Plectrodus mirabilis* (fig. 535), have also been detected, together with some specimens of *Pteraspis Ludensis*. As usual in bone-beds, the teeth and bones are, for the most part, fragmentary and rolled.

Fig. 533.

Onchus tenuistriatus, Agass.
Bone-bed. Upper Silurian; Ludlow.

Fig 534.



Shagreen scales of a placoid fish, *Thecodus Parvidens*, Ag. Bone-bed. Upper Ludlow.

Fig. 535.

Plectrodus mirabilis, Agass.
Bone-bed. Upper Ludlow.

Grey Sandstone and Mudstone, &c.—The next subdivision of the Upper Ludlow consists of grey calcareous sandstone, or very commonly a micaceous rock, decomposing into soft mud, and contains, besides the shells mentioned at p. 456, *Lingula cornea*, *Orthis orbicularis*, a round variety of *O. elegantula* (fig. 536), *Modiolopsis platyphylla*, *Grammysia cingulata*, all characteristic of the Upper Ludlow. The lowest or mudstone beds contain *Rhynchonella navicula* (fig. 537), which is common to this bed and the Lower Ludlow. As usual in Palæozoic strata older than the coal, the brachiopodous or palliobranchiate mollusca greatly outnumber the lamellibranchiate (see p. 469); but the latter are by no means unrepresented. Among other genera, for example, we observe *Avicula* and *Pterinea*, *Cardiola*, *Ctenodonta* (sub-genus of *Nucula*), *Orthonota*, *Modiolopsis*, and *Palæarca*.

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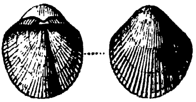
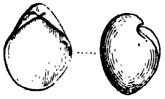
[1] Murchison's Siluria, p. 140.

Fig. 536.



Orthis elegantula, Dalm.
Var. *Orbicularis*, Sow. Upper Ludlow.

Fig. 537.

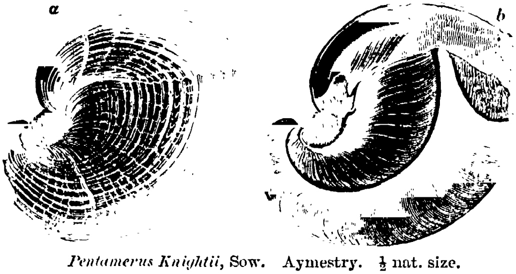


Rhynchonella navicula, Sow.
Ludlow Beds.

Some of the Upper Ludlow sandstones are ripple-marked, thus affording evidence of gradual deposition; and the same may be said of the accompanying fine argillaceous shales, which are of great thickness, and have been provincially named 'mudstones.' In some of these shales stems of crinoidea are found in an erect position, having evidently become fossil on the spots where they grew at the bottom of the sea. The facility with which these rocks, when exposed to the weather, are resolved into mud, proves that, notwithstanding their antiquity, they are nearly in the state in which they were first thrown down.

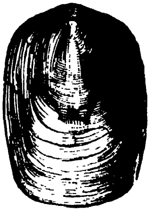
Lower Ludlow Beds.—The chief mass of this formation consists of a dark grey argillaceous shale with calcareous concretions, having a maximum thickness of 1,000 feet. In some places, and especially at Aymestry in Herefordshire, a subcrys-

Fig. 538.



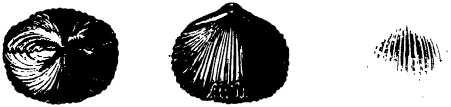
Pentamerus Knightii, Sow. Aymestry. ½ nat. size.
a. View of both valves united. *b*. Longitudinal section through both valves, showing the central plates or septa.

Fig. 539.



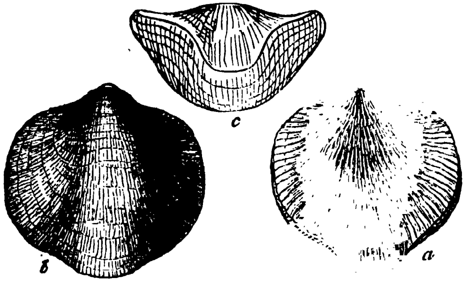
Lingula Lewisii, Sow. Abberley Hills.

talline and argillaceous limestone, sometimes 50 feet thick, overlies the shale. Sir R. Murchison classes this Aymestry limestone as holding an intermediate position between the Upper and Lower Ludlow; but Mr. Lightbody remarks that at Mocktrie near Leintwardine the Lower Ludlow shales, with their characteristic fossils, occur both above and below a similar limestone. This limestone around Aymestry and Sedgeley is distinguished by the abundance of *Pentamerus Knightii*, Sow. (fig. 538), also found in the Wenlock limestone and shale. This genus of brachiopoda was first found in Silurian strata, and is exclusively a palæozoic form. The name was derived from πεντε, *pente*, five, and μερος, *meros*, a part, because both valves are divided by a central septum, making four chambers, and in one valve the septum itself contains a small chamber, making five. The size of these septa is enormous compared with those of any other brachiopod shell; and they must nearly have divided the animal into two equal halves; but they are, nevertheless, of the same nature as the septa or plates which are found in the interior



Rhynchonella (*Terebratula*) *Wilsoni*, Sow. Aymestry.

Fig. 541.

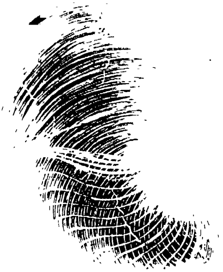


Atrypa reticularis, Linn. (*Terebratula affinis*, Min. Con.). Aymestry.
a. Upper valve. *b*. Lower valve. *c*. Anterior margin of the valves.

of *Spirifera*, *Uncites*, and many other shells of this order. Messrs. Murchison and De Verneuil discovered this species dispersed in myriads through a white limestone of Upper Silurian age, on the banks of the Is, on the eastern flank of the Urals in Russia, and a similar species is frequent in Sweden.

Three other abundant shells in the Aymestry limestone are, 1st, *Lingula Lewisii* (fig. 539); 2nd, *Rhynchonella Wilsoni*, Sow. (fig. 540), which is also common to the Lower Ludlow and Wenlock limestone; 3rd, *Atrypa reticularis*, Linn. (fig. 541), which has a very wide range, being found in every part of the Upper Silurian system, and even ranging up into the Middle Devonian series.

Fig. 542.

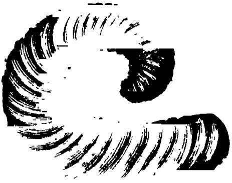


Phragmoceras ventricosum, J. Sow. (*Orthoceras ventricosum*, Stein). Aymestry. ¼ nat. size.

The Aymestry Limestone contains many shells, especially brachiopoda, corals, trilobites, and other fossils, amounting on the whole to 74 species, all except three or four being common to the beds either above or below.

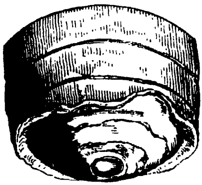
The Lower Ludlow Shale contains, among other fossils, many large cephalopoda not known in newer rocks, as the *Phragmoceras* of Broderip, and the *Lituites* of Breynius (see figs. 542, 543). The latter is partly straight and partly convoluted in a very flat spire. The *Orthoceras Ludense* (fig. 544), as well as the cephalopod last mentioned, occurs in this member of the series.

Fig. 543.



Lituites (Trochoceras) giganteus, J. Sow. Near Ludlow; also in the Aymestry and Wenlock Limestones. ¼ nat. size.

Fig. 544.



Fragment of *Orthoceras Ludense*, J. Sow. Leintwardine, Shropshire.

A species of Graptolite, *G. priodon*, Bronn. (fig. 554, p. 465), occurs plentifully in the Lower Ludlow. This fossil, referred, though somewhat doubtfully, to a form of hydrozoid or sertularian polyp, has not yet been met with in strata above the Silurian.

Star-fish, as Sir R. Murchison points out, are by no means rare in the Lower Ludlow rock. These fossils, of which 6 extinct genera are now known in the Ludlow series represented by 18 species, remind us of various living forms now found in our British seas, both of the families *Asteriadæ* and *Ophiuridæ*.

Dates of the Discovery of different Classes of Fossil Vertebrata; showing the gradual progress made in tracing them to rocks of higher antiquity.

	Year	Formations	Geographical Localities
Mammalia	1798	Upper Eocene	Paris (Gypsum of Montmartre).[1]
	1818	Lower Oolite	Stonesfield.[2]
	1847	Upper Trias	Stuttgart.[3]
Aves	1782	Upper Eocene	Paris (Gypsum of Montmartre).[4]
	1839	Lower Eocene	Isle of Sheppey (London Clay).[5]
	1854	” ”	Woolwich Beds.[6]
	1855	” ”	Meudon (Plastic Clay).[7]
	1858	Chloritic series or Upper Greensand.	Cambridge.[8]
	1863	Upper Oolite	Solenhofen.[9]
Reptilia (including Amphibia)	1810	Permian (Zechstein)	Thuringia.[10]
	1844	Carboniferous	Saarbrück, near Trèves.[11]
Pisces	1709	Middle Permian (Kupfer-schiefer).	Thuringia.[12]
	1793	Lower Carboniferous	Glasgow.[13]
	1828	Devonian	Caithness.[14]
	1840	Upper Ludlow	Ludlow.[15]
	1859	Lower Ludlow	Leintwardine.[16]

[1] George Cuvier, Bulletin Soc. Philom. xx.

[2] In 1818, Cuvier, visiting the Museum of Oxford, decided on the mammalian character of a jaw from Stonesfield. See also above, p. 333.

[3] Plieninger, Prof. See above, p. 356.

[4] Cuvier, Ossemens Foss., Art. 'Oiseaux.'

[5] Owen, Prof., Geol. Trans., 2nd series, vol. vi. p. 203. 1839.

[6] Upper part of the Woolwich beds. Prestwich, Quart. Geol. Journ., vol. x. p. 157.

[7] *Gastornis Parisiensis.* Owen, Quart. Geol. Journ., vol. xii. p. 204. 1856.

[8] Coprolitic bed, in the Upper Greensand. See above, p. 283.

[9] The *Archæopteryx macrura*, Owen. See above, p. 325.

[10] The fossil monitor of Thuringia (*Protorosaurus Speneri*, V. Meyer) was figured by Spener, of Berlin, in 1810. (Miscel. Berlin.)

[11] See above, p. 397.

[12] Memorabilia Saxoniæ Subterr., Leipsic, 1709.

[13] History of Rutherglen, by Rev. David Ure, 1793.

[14] Sedgwick and Murchison, Geol. Trans., 2nd series, vol. iii. p. 141. 1828.

[15] Sir. R. Murchison. See above, p. 457.

[16] See p. 462.

Obs.—The evidence derived from footprints, though often to be relied on, is omitted in the above table, as being less exact than that founded on bones and teeth.

Oldest known fossil fish.—Until 1859 there was no example of a fossil fish older than the bone-bed of the Upper Ludlow;

but in that year a specimen of Pteraspis was found at Church Hill, near Leintwardine in Shropshire, by Mr. J. E. Lee of Caerleon, F.G.S., in shale below the Aymestry limestone, associated with fossil shells of the Lower Ludlow formation—shells which differ considerably from those characterising the Upper Ludlow already described. This discovery is of no small interest as bearing on the theory of progressive development, because, according to Professor Huxley, the genus Pteraspis is allied to the sturgeon, and therefore by no means of low grade in the piscine class.

It is a fact well worthy of notice that no remains of vertebrata have yet been met with in any strata older than the Lower Ludlow.

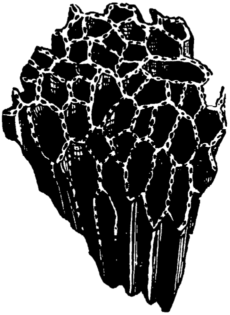
When we reflect on the hundreds of Mollusks, Echinoderms, Trilobites, Corals, and other fossils already obtained from the Silurian formations, Upper, Middle, and Lower, we may well ask, whether any set of fossiliferous rocks newer in the series were ever studied with equal diligence, and over so vast an area, without yielding a single ichthyolite. Yet we must hesitate before we accept, even on such evidence, so sweeping a conclusion, as that the globe, for ages after it was inhabited by all the great classes of invertebrata, remained wholly untenanted by vertebrate animals.

In the preceding Table (p. 461) a few dates are set before the reader of the discovery of different classes of animals in ancient rocks, to enable him to perceive at a glance how gradual has been our progress in tracing back the signs of vertebrata to formations of high antiquity. Such facts may be useful in warning us not to assume too hastily that the point which our retrospect may have reached at the present moment can be regarded as fixing the date of the first introduction of any one class of beings upon the earth.

2. **Wenlock Formation.**—We next come to the Wenlock formation, which has been divided (see Table, p. 455) into *a*, Wenlock Limestone and Wenlock shale, and *b*, Woolhope limestone and Denbighshire grits.

a. Wenlock limestone.—This limestone, otherwise well known to collectors by the name of the Dudley Limestone, forms a continuous ridge in Shropshire, ranging for about 20 miles from S.W. to N.E., about a mile distant from the nearly parallel escarpment of the Aymestry limestone. This ridgy prominence is due to the solidity of the rock, and to the softness of the shales above and below it. Near Wenlock it consists of thick masses of grey subcrystalline limestone, replete with corals, encrinites, and trilobites. It is essentially of a concretionary nature; and the concretions, termed 'ball-stones' in Shropshire, are often enormous, even 80 feet in diameter. They are composed chiefly of carbonate of lime, the surrounding rock being more or less argillaceous.[1] Sometimes in the Malvern Hills this limestone, according to Professor Phillips, is oolitic.

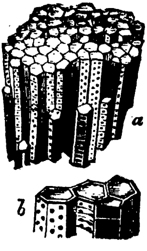
Fig. 545.



Halysites catenularius, Linn. sp. Upper and Lower Silurian.

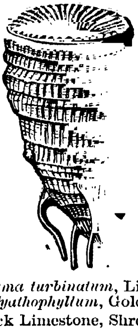
Among the corals in which this formation is so rich, 53 species being known, the 'chain-coral,' *Halysites catenularius* (fig. 545), may be pointed out as one very easily recognised, and widely spread in Europe, ranging through all parts of the Silurian group, from the Aymestry limestone to near the bottom of the Llandeilo rocks. Another coral, the *Favosites Gothlandica* (fig. 546), is also met with in profusion in large hemispherical masses, which break up into columnar and prismatic fragments, like that here figured (fig. 546, *b*). Another common form in the Wenlock limestone is the *Omphyma turbinatum* (fig. 547), which, like many of its modern companions, reminds us of some cup-corals; but all the Silurian genera belong to the palæozoic type before mentioned (p. 425), exhibiting the quadripartite arrangement of the septal-lamellæ within the cup.

Fig. 546.



Favosites Gothlandica, Lam. Dudley.
a. Portion of a large mass; less than the natural size.
b. Magnified portion, to show the pores and the partitions in the tubes.

Fig. 547.



Omphyma turbinatum, Linn. sp. (*Cyathophyllum*, Goldf.) Wenlock Limestone, Shropshire.

Among the numerous Crinoids, several peculiar species of *Cyathocrinus* (for genus, see figs. 486, 487, p. 427) contribute their dismembered calcareous stems, arms, and cups towards the composition of the Wenlock limestone. Of Cystideans there are a few very remarkable forms, most of them peculiar to the Upper Silurian formation; as, for example, the *Pseudocrinites*, which was furnished with pinnated fixed arms,[1] as represented in the annexed figure (fig. 548).

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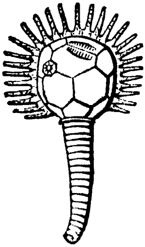
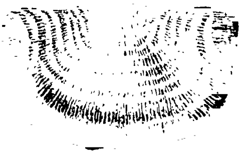
[1] Murchison's Siluria, chap. vi.

Fig. 548.



Pseudocrinites bifasciatus, Pearce.
Wenlock Limestone, Dudley.

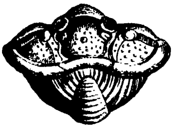
Fig. 549.



Strophomena (Leptæna) depressa, Sow.
Wenlock and Ludlow Rocks.

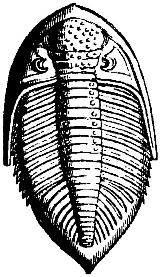
The Brachiopoda are, many of them, of the same species as those of the Aymestry limestone; as, for example, *Atrypa reticularis* (fig. 541, p. 459), and *Strophomena depressa* (fig. 549); but the latter species ranges also from the Ludlow rocks, through the Wenlock shale, to the Caradoc sandstone.

Fig. 550.



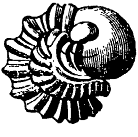
Calymene Blumenbachii, Brong.
Ludlow, Wenlock, and Bala Beds.

Fig. 551.



Phacops (Asaphus) caudatus, Brong.
Wenlock and Ludlow Rocks.

Fig. 552.



Sphærexochus mirus, Beyrich; coiled up, Wenlock Limestone, Dudley; also found in Ohio, N. America.

The Crustaceans are represented almost exclusively by Trilobites, which are very conspicuous, 22 being peculiar. The

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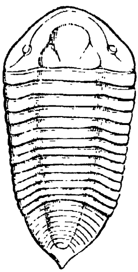
[1] E. Forbes, Mem. Geol. Survey, vol. ii. p. 496.

Calymene Blumenbachii, called the 'Dudley Trilobite,' was known to collectors long before its true place in the animal kingdom was ascertained. It is often found coiled up like the common *Oniscus* or wood-louse, and this is so usual a circumstance among certain genera of trilobites as to lead us to conclude that they must have habitually resorted to this mode of protecting themselves when alarmed. The other common species is the *Phacops caudatus* (*Asaphus caudatus*), Brong. (see fig. 551), which is conspicuous for its large size and flattened form. *Sphærexochus mirus* (fig. 552) is almost globular when rolled up, the forehead or glabellum of this species being extremely inflated. The *Homalonotus*, a form of Trilobite in which the tripartite division of the dorsal crust is almost lost (see fig. 553), is very characteristic of this division of the Silurian series.

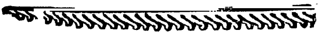
Wenlock shale.—This, observes Sir R. Murchison, is infinitely the largest and most persistent member of the Wenlock formation, for the limestone often thins out and disappears. The shale, like the Lower Ludlow, often contains elliptical concretions of impure earthy limestone. In the Malvern district it is a mass of finely levigated argillaceous matter, attaining, according to Professor Phillips, a thickness of 640 feet; but it is sometimes more than 1,000 feet thick in Wales, and is worked for flagstones and slates. The prevailing fossils, besides corals and trilobites, and some crinoids, are several small species of *Orthis*, *Cardiola*, and numerous thin-shelled species of *Orthoceratites*.

Fig. 553.



Homalonotus delphinocephalus, Konig.
Wenlock Limestone,
Dudley Castle.

Fig. 554.



Graptolithus priodon, Bronn.
Ludlow and Wenlock Shales.

About six species of *Graptolite*, a peculiar group of sertularian-like fossils before alluded to (p. 460) as being confined to Silurian rocks, occur in this shale. Of this genus, which is very characteristic of the Lower Silurian, I shall again speak in the sequel (p. 472).

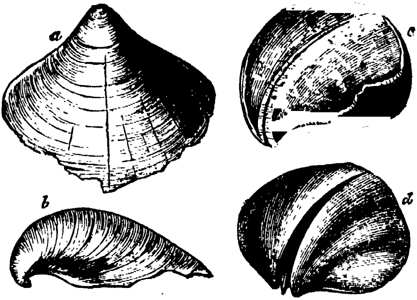
b. Woolhope beds.—Though not always recognised as a separate subdivision of the Wenlock, the Woolhope beds which underlie the Wenlock shale are of great importance. Usually they occur as massive or nodular limestones, underlaid by a fine shale or flagstone; and in other cases, as in the noted Denbighshire sandstones, as a coarse grit of very great thickness. This grit forms mountain ranges through North and South Wales, and is generally marked by the great sterility of the soil where it occurs. It contains the usual Wenlock fossils, but with the addition of some common in the uppermost Ludlow rock, such as *Chonetes lata* and *Bellerophon trilobatus.* The chief fossils of the Woolhope limestone are *Illænus Barriensis, Homalonotus delphinocephalus* (fig. 553), *Strophomena imbrex,* and *Rhynchonella Wilsoni* (fig. 540). The latter attains in the Woolhope beds an unusual size for the species, the specimens being sometimes twice as large as those found in the Wenlock limestone.

In some places below the Wenlock formation there are shales of a pale or purple colour which near Tarannon attain a thickness of about 1,000 feet; they can be traced through Radnor and Montgomery to North Wales, according to Messrs. Jukes and Aveline. By the latter geologist they have been identified with certain shales above the May Hill Sandstone near Llandovery, but owing to the extreme scarcity of fossils their exact position remains doubtful.

3. **Llandovery Group—Beds of Passage.**—We now come to beds respecting the classification of which there has been much difference of opinion, and which in fact must be considered as beds of passage between Upper and Lower Silurian. I formerly adopted the plan of those who class them as Middle Silurian; but they are scarcely entitled to this distinction, since, after about 1,400 Silurian species have been compared, the number peculiar to the group in question only gives them an importance equal to such minor subdivisions as the Ludlow or Bala groups. I therefore prefer to regard them as the base of the Upper Silurian, to which group they are linked by more than twice as many species as to the Lower Silurian. By this arrangement the line of demarcation between the two great divisions, though confessedly arbitrary, is less so than by any other. They are called Llandovery Rocks, from a town in South Wales in the neighbourhood of which they are well developed, and where, especially at a hill called Noeth Grüg, in spite of several faults their relations to one another can be clearly seen.

a. Upper Llandovery or May Hill Sandstone.—The May Hill group, which has also been named 'Upper Llandovery' by Sir R. Murchison, ranges from the west of the Longmynd to Builth, Llandovery, and Llandeilo, and to the sea in Marlow's Bay, where it is seen in the cliffs. It consists of brownish and yellow sandstones with calcareous nodules, having sometimes a conglomerate at the base derived from the waste of the Lower Silurian rocks. These May Hill beds were formerly supposed to be part of the Caradoc formation, but their true position was determined by Professor Sedgwick[1] to be at the base of the Upper Silurian Proper. The more calcareous portions of the rock have been called the Pentamerus limestone, because *Pentamerus oblongus* (fig. 555) is very abundant in them. It is usually accompanied by *P.* (*Stricklandinia*) *lirata* (fig. 556); both forms have a wide geographical range, being also met with in the same part of the Silurian series in Russia and the United States.

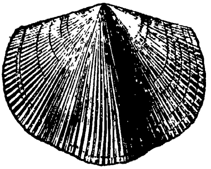
Fig. 555.



Pentamerus oblongus, Sow. Upper and Lower Llandovery bed

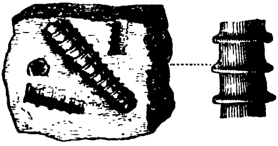
a, b. Views of the shell itself, from figures in Murchison's 'Sil. Syst.'
c. Cast with portion of shell remaining, and with the hollow of the central septum filled with spar.
d. Internal cast of a valve, the space once occupied by the septum being represented by a hollow in which is seen a cast of the chamber within the septum.

Fig. 556.



Stricklandinia (*Pentamerus*) *lirata*, Sow.

Fig. 557.



Tentaculites annulatus, Schlot. Interior casts in sandstone. Upper Llandovery, Eastnor Park, near Malvern. Natural size and magnified.

About 228 species of fossils are known in the May Hill division, more than half of which are Wenlock species. They consist of trilobites of the genera *Illænus* and *Calymene*; Brachiopods of the genera *Orthis*, *Atrypa*, *Leptæna*, *Pentamerus*, *Strophomena*, and others; Gasteropods of the genera *Turbo*,

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[1] 1853. Quart. Geol. Journ., vol. ix. p. 215.

Murchisonia (for genus, see fig. 576, p. 479), and *Bellerophon;* also Pteropods of the genus *Conularia.* The Brachiopoda, of which there are 66 species, are almost all Upper Silurian.

Among the fossils occurring in the May Hill shelly sandstone at Malvern, is *Tentaculites annulatus* (fig. 557), an annelid probably allied to *Serpula.*

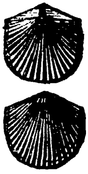
Lower Llandovery Rocks.—Below the May Hill Group are the Lower Llandovery Rocks, which consist chiefly of hard slaty rocks, and beds of conglomerate from 600 to 1,000 feet in thickness. The fossils, which are somewhat rare in the lower beds, consist of 128 known species, only 11 of which are peculiar, 83 being common to the May Hill group above, and 93 common to the rocks below. *Stricklandinia* (*Pentamerus*) *levis,* which is common to the Lower Llandovery, becomes rare in the Upper, while *Pentamerus oblongus* (fig. 555), which is the characteristic shell of the Upper Llandovery, occurs but seldom in the Lower.

LOWER SILURIAN ROCKS.

The Lower Silurian has been divided into, 1st, the Bala Group; 2nd, the Llandeilo Flags; and, 3rdly, the Arenig or Lower Llandeilo formation.

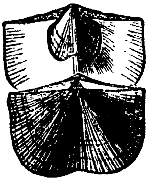
Bala and Caradoc Beds.—The Caradoc sandstone was originally so named by Sir R. I. Murchison from the mountain called Caer Caradoc in Shropshire; it consists of shelly sandstones of great thickness, and sometimes containing much calcareous matter. The rock is frequently laden with the beautiful trilobite called by Murchison *Trinucleus concentricus* (see fig. 562, p. 470), which ranges from the base to the summit of the formation, usually accompanied by *Strophomena grandis* (fig. 560) and *Orthis vespertilio* (fig. 559), with many other fossils.

Fig. 558.



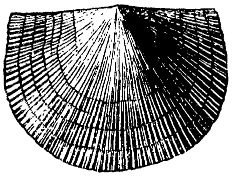
Orthis tricenaria, Conrad.
New York; Canada.
½ nat. size.

Fig. 559.



Orthis vespertilio, Sow.
Shropshire; N. and S. Wales
½ nat. size.

Fig. 560.



Orthis (Strophomena) grandis, Sow. ⅔ nat. size.
Caradoc Beds, Horderley, Shropshire; and Coniston, Lancashire.

Brachiopoda.—Nothing is more remarkable in these beds and in the Silurian strata generally of all countries than the preponderance of Brachiopoda over other forms of mollusca. Their proportional numbers can by no means be explained by supposing them to have inhabited seas of great depth, for the contrast between the palæozoic and the present state of things has not been essentially altered by the late discoveries made in our deep-sea dredgings. We find the living Brachiopoda so rare as to form about one forty-fourth of the whole bivalve fauna; whereas in the Lower Silurian rocks of which we are now about to treat, and where the Brachiopoda reach their maximum, they are represented by more than twice as many species as the Lamellibranchiate bivalves.

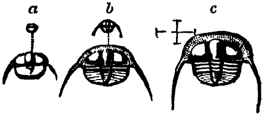
There may, indeed, be said to be a continued decrease of the proportional number of this lower tribe of mollusca as we proceed from older to newer rocks. In the British Devonian, for example, the Brachiopoda number 99, the Lamellibranchiata 58; while in the Carboniferous their proportions are more than reversed, the Lamellibranchiata numbering 334 species, and the Brachiopoda only 157. In the Secondary or Mesozoic formations the preponderance of the higher grade of bivalves becomes more and more marked, till in the Tertiary or Cainozoic strata it approaches that observed in the living creation.

While on this subject it may be useful to the student to know that a Brachiopod differs from ordinary bivalves, mussels, cockles, &c., in being always equal-sided and never quite equivalved; the form of each valve being symmetrical, it may be divided into two equal parts by a line drawn from the apex to the centre or front of the margin.

Trilobites.—In the Bala and Caradoc beds the trilobites reach their maximum, being represented by 111 species referred to 23 genera.

Burmeister, in his work on the organisation of trilobites, supposes that they swam at the surface of the water in the open sea and near coasts, feeding on smaller marine animals, and had the power of rolling themselves into a ball as a defence against injury. He was also of opinion that they underwent various transformations analogous to those of living crustaceans. M. Barrande, author of an admirable work on the Silurian rocks of Bohemia, confirms the doctrine of their metamorphosis, having traced more than twenty species through different stages of growth from the young state just after its escape from the egg to the adult form. He has followed some of them from a point in which they show no eyes, no joints, or body rings, and no distinct tail, up to the complete form with the full number of segments. This change is brought about before the animal has attained a tenth part of its full dimensions, and hence such minute and delicate specimens are rarely met with. Some of his figures of the metamorphoses of the common *Trinucleus* are copied in the annexed woodcuts (figs. 561, 562). In 1870 Mr. Billings suspected, from the appearance of a specimen found in Canada, that the trilobite was provided with eight legs; but Professor Dana, having thoroughly examined the fossil, came to the conclusion that the organs were not legs, but the semi-calcified arches in the membrane of the ventral surface to which the foliaceous appendages or legs were attached.[1]

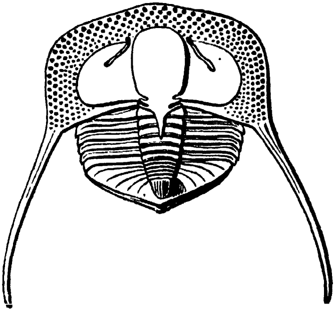
Fig. 561.



Young individuals of *Trinucleus concentricus* (*T. ornatus*, Barr.).

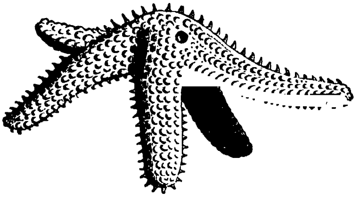
a. Youngest state. Natural size and magnified: the body rings not at all developed.
b. A little older. One thorax joint.
c. Still more advanced. Three thorax joints. The fourth, fifth, and sixth segments are successively produced, probably each time the animal moulted its crust.

Fig. 562.



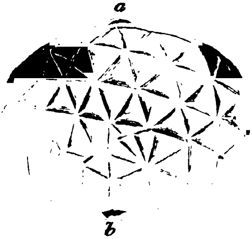
Trinucleus concentricus, Eaton.
Syn. *T. Caractaci*, Murch.
Ireland; Wales; Shropshire; N. America; Bohemia.

Fig. 563.



Palæaster asperimus, Salt.
Caradoc, Welshpool.

Fig. 564.



Echinosphærites balticus Eichwald.
(Of the family *Cystideæ*.)
a. Mouth.
b. Point of attachment of stem.
Lower Silurian S. and N. Wales.

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[1] Nature, vol. iv. 1871, p. 152.

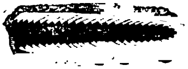
It has been ascertained that a great thickness of slaty and crystalline rocks of South Wales, as well as those of Snowdon and Bala in North Wales, which were first supposed to be of older date than the Silurian sandstones and mudstones of Shropshire, are in fact identical in age, and contain the same organic remains. At Bala in Merionethshire, a limestone rich in fossils occurs, in which two genera of star-fish, *Protaster* and *Palæaster*, are found, the latter (fig. 563) being almost as uncompressed as if found just washed up on the sea-beach. Besides the star-fish there occur many of those peculiar bodies called *Cystideæ*. They are the *Sphæronites* of old authors, and were considered by Professor E. Forbes as intermediate between the crinoids and echinoderms. The *Echinosphærites* here represented (fig. 564) is characteristic of the Caradoc beds in Wales, and of their equivalents in Sweden and Russia.

With it have been found several other genera of the same family, such as *Sphæronites*, *Hemicosmites*, &c. Among the mollusca are Pteropods of the genus *Conularia* of large size (for genus, see fig. 527, p. 449). About 11 species of Graptolites are reckoned as belonging to this formation; they are chiefly found in peculiar localities where black mud abounds. The formation, when traced into South Wales and Ireland, assumes a greatly altered mineral aspect, but still retains its characteristic fossils. The known fauna of the Bala group comprises 565 species, 352 of which are peculiar, and 93, as before stated, are common to the overlying Llandovery rocks. It is worthy of remark that, when it occurs under the form of trappean tuff (volcanic ashes of De la Beche), as in the crest of Snowdon, the peculiar species which distinguish it from the Llandeilo beds are still observable. The formation generally appears to be of shallow-water origin, and in that respect is contrasted with the group next to be described. Professor Ramsay estimates the thickness of the Bala beds, including the contemporaneous volcanic rocks, stratified and unstratified, as being from 10,000 to 12,000 feet.

Llandeilo Flags.—The Lower Silurian strata were originally divided by Sir R. Murchison into the upper group already described under the name of Caradoc Sandstone, and a lower one, called, from a town in Caermarthenshire, the *Llandeilo* flags. The last-mentioned strata consist of dark-coloured argillaceous and micaceous flags, frequently calcareous, with a great thickness of shales, generally black, below them. The same beds are also seen at Abereiddy Bay in Pembrokeshire and at Builth in Radnorshire, where they are interstratified with volcanic matter.

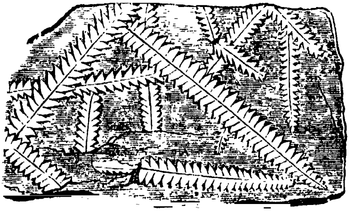
A still lower part of the Llandeilo rocks consists of a black carbonaceous slate of great thickness, frequently containing sulphuret of iron, and sometimes, as in Dumfriesshire, beds of anthracite. It has been conjectured that this carbonaceous matter may be due in great measure to large quantities of embedded animal remains, for the number of Graptolites included in these slates was certainly very great. In Great Britain 15 genera and about 90 species of Graptolites occur in the Llandeilo flags and underlying Arenig beds. The double Graptolites, or those with two rows of cells, such as *Diplograpsus* (fig. 566), are conspicuous.

Fig. 565.



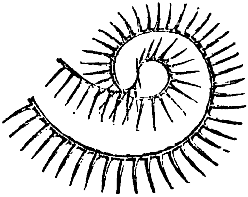
Didymograpsus (Graptolites *Murchisoni*, Beck.
Llandeilo flags, Wales.

Fig. 566.



Diplograpsus pristis, Hisinger.
Llandeilo beds, Waterford.

Fig. 567.



Rastrites peregrinus, Barrande.
Scotland; Bohemia; Saxony.
Llandeilo flags.

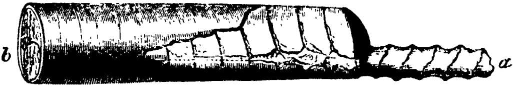
Fig. 568.

Diplograpsus folium, Hisinger.
Dumfriesshire; Sweden.
Llandeilo flags.

The Brachiopoda of the Llandeilo flags, which number 47 species, are in the main the same as those of the Caradoc Sandstone, but the other mollusca are mostly of different species.

In Europe generally, as, for example, in Sweden and Russia, no shells are so characteristic of this formation as Orthoceratites, usually of great size, and with a wide siphuncle placed on one side instead of being central (see fig. 569). Among other Cephalopods in the Llandeilo flags is Cyrtoceras (see p. 482), a slightly curved Orthoceras having the siphuncle on the dorsal edge; in the same beds also are found Bellerophon (see fig. 497, p. 430) and some Pteropod shells (*Conularia*, *Theca*, &c.); also in spots where sand abounded lamellibranchiate bivalves of large size. The Crustaceans were plentifully represented by the Trilobites, which appear to have swarmed in the Silurian seas just as crabs and shrimps do in our own; no less than 263 species have been found in the British Silurian fauna. The genera *Asaphus* (fig. 570), *Ogygia* (fig. 571) and *Trinucleus* (p. 470) form a marked feature of the rich and varied Trilobitic fauna of this age.

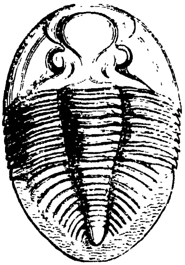
Fig. 569.



Orthoceras duplex, Wahlenberg. Russia and Sweden.
(From Murchison's 'Siluria.')

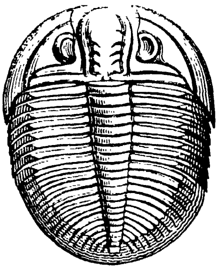
a. Lateral siphuncle laid bare by the removal of a portion of the chambered shell.
b. Continuation of the same seen in a transverse section of the shell.

Fig. 570.



Asaphus tyrannus, Murch.
Llandeilo; Bishop's Castle; &c.

Fig. 571.

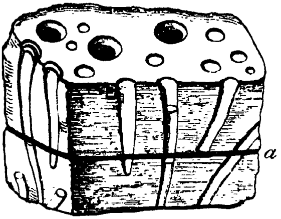


Ogygia Buchii, Burm.
Syn. *Asaphus Buchii*, Brongn.
Builth, Radnorshire; Llandeilo, Caermarthenshire.

Beneath the black slates above described of the Llandeilo formation, graptolites are still found in great variety and abundance, and the characteristic genera of shells and trilobites of the Lower Silurian rocks are still traceable downwards, in Shropshire, Cumberland, and North and South Wales, through a vast thickness of shaly beds, in some districts interstratified with trappean rocks of contemporaneous origin; these consist of tuffs and lavas, the tuffs being formed of such materials as are ejected from craters and deposited immediately on the bed of the ocean, or washed into it from the land. According to Professor Ramsay, their thickness is about 3,300 feet in North Wales, including those of the Lower Llandeilo about to be described, and they also attain a great thickness in Pembrokeshire in South Wales. The lavas are felspathic, and of porphyritic structure, and, according to the same authority, of an aggregate thickness of 2,500 feet.

Arenig or Stiper-Stones Group (*Lower Llandeilo of Murchison*).—Next in the descending order, and forming the base of the series, are the shales and sandstones in which the quartzose rocks called Stiper-Stones in Shropshire occur. Originally these Stiper-Stones were only known as arenaceous quartzose strata in which no organic remains were conspicuous, except the tubular burrows of annelids (see fig. 572, *Arenicolites linearis*), which are remarkably common in the Lowest Silurian in Shropshire, the north-west Highlands of Scotland, and in the State of New York in America. They have already been alluded to as occurring by thousands in the white quartzose Lower Silurian strata unconformably overlying the Cambrian in the mountain of Queenaig in Sutherlandshire (see fig. 82, p. 89). I have seen similar burrows now made on the retiring of the tides in the sands of the Bristol Channel, near Minehead, by lobworms which are dug out by fishermen and used as bait. When the term Silurian was given by Sir R. Murchison, in 1835, to the whole series, he considered the Stiper-Stones as the base of the Silurian system; but no fossil fauna had then been obtained, such as could alone enable the geologist to draw a line between this member of the series and the Llandeilo flags above, or the vast thickness of rock below which was seen to form the Longmynd hills, and was called 'unfossiliferous graywacke.' Professor Sedgwick had described, in 1843, strata now ascertained to be of the same age, as largely developed in the Arenig mountain in Merionethshire; and the Skiddaw slates in the Lake-District of Cumberland, studied by the same author, were of corresponding date, though the number of fossils was, in both cases, too few for the determination of their true chronological relations. The subsequent researches of Messrs. Sedgwick and Harkness in Cumberland, and of Sir R. I. Murchison and the Government surveyors in Shropshire, have increased the species to more than sixty. These were examined by Mr. Salter, and shown in the third edition of 'Siluria' (p. 52, 1859) to be quite

Fig. 572.



Arenicolites linearis, Hall.
Arenig beds, Stiper-stones.
a. Parting between the beds, or planes of bedding.

It would be unsafe to rely on the mere thickness of the strata, considered apart from the great fluctuations in organic life which took place between the era of the Llandeilo and that of the Ludlow formation, especially as the enormous pile of Silurian rocks observed in Great Britain (in Wales more particularly) is derived in great part from igneous action, and is not confined to the ordinary deposition of sediment from rivers or the waste of cliffs.

In volcanic archipelagoes, such as the Canaries, we see the most active of all known causes, aqueous and igneous, simultaneously at work to produce great results in a comparatively moderate lapse of time. The outpouring of repeated streams of lava—the showering down upon land and sea of volcanic ashes—the sweeping seaward of loose sand and cinders, or of rocks ground down to pebbles and sand, by rivers and torrents descending steeply-inclined channels—the undermining and eating away of long lines of sea-cliff exposed to the swell of a deep and open ocean—these operations combine to produce a considerable

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[1] Trans. Brit. Assoc. 1866. Proc. Liverpool Geol. Soc. 1869.

volume of superimposed matter, without there being time for any extensive change of species. Nevertheless, there would seem to be a limit to the thickness of stony masses formed even under such favourable circumstances, for the analogy of tertiary volcanic regions lends no countenance to the notion that sedimentary and igneous rocks, 25,000, much less 45,000 feet thick, like those of Wales, could originate while one and the same fauna should continue to people the earth. If, then, we allow that about 25,000 feet of matter may be ascribed to one system, such as the Silurian, as above described, we may be prepared to discover in the next series of subjacent rocks a distinct assemblage of species, or even in great part of genera, of organic remains. Such appears to be the fact; and I shall therefore conclude with the Arenig beds my enumeration of the Silurian formations in Great Britain, and proceed to say something of their foreign equivalents, before treating of rocks older than the Silurian.

Silurian strata of the Continent of Europe.—When we turn to the Continent of Europe, we discover the same ancient series occupying a wide area, but in no region as yet has it been observed to attain great thickness. Thus, in Norway and Sweden, the total thickness of strata of Silurian age is considerably less than 1,000 feet, although the representatives both of the Upper and Lower Silurian of England are not wanting there. In Russia the Silurian strata, so far as they are yet known, seem to be even of smaller vertical dimensions than in Scandinavia, and they appear to consist chiefly of the Llandovery group, or of a limestone containing *Pentamerus oblongus*, below which are strata with fossils corresponding to those of the Llandeilo beds of England. The lowest rock with organic remains yet discovered is 'the Ungulite or Obolus grit' of St. Petersburg, probably coeval with the Llandeilo flags of Wales.

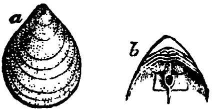
The shales and grits near St. Petersburg, above alluded to, contain green grains in their sandy layers, and are in a singularly unaltered state, taking into account their high antiquity. The prevailing brachiopods consist of the *Obolus* or Ungulite of Pander, also found in the Wenlock limestone of England, and a *Siphonotreta*, common to both the Upper and Lower Silurian of England (figs. 574, 575).

Among the green grains of the sandy strata above mentioned, Prof. Ehrenberg announced in 1854 his discovery of remains of foraminifera. These are casts of the cells; and amongst five or six forms three are considered by him as referable to existing genera (e. g. *Textularia*, *Rotalia*, and *Guttulina*).

In the year 1846, as before stated, M. Joachim Barrande, after ten years' exploration of Bohemia, and after collecting more than a thousand species of fossils, had ascertained the existence in that country of three distinct faunas below the Devonian. To his first fauna, which was older than any then known in this country, he gave the name of Étage C ; his two first stages A and B consisting of crystalline and metamorphic rocks and unfossiliferous schists. This Étage C or primordial zone proved afterwards to be the equivalent of the Upper Cambrian, to be described in the next chapter. The second fauna, Étage D, tallies with Murchison's Lower Silurian as originally defined by him when no fossils had been discovered below the Stiper-Stones. The third fauna, Étages E F G, agrees with the Upper Silurian of the same author. Barrande, without Government assistance, had undertaken single-handed the geological survey of Bohemia, the fossils previously obtained from that country having scarcely exceeded 20 in number, whereas he had already acquired in 1850 no less than 1,100 species, namely, 250 crustaceous (chiefly Trilobites), 250 cephalopods, 160 gasteropods and pteropods, 130 acephalous mollusks, 210 brachiopods, and 110 corals and other fossils.

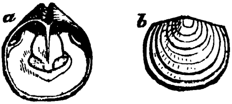
Shells of the lowest known Fossiliferous Beds in Russia.

Fig. 574.



Siphonotreta unguiculata, Eichwald.
From the Lowest Silurian sandstone 'Obolus grits,' of Petersburg.
a. Outside of perforated valve.
b. Interior of same, showing the termination of the foramen within. (Davidson.)

Fig. 575.



Obolus Apollinis, Eichwald.
From the same locality.
a. Interior of the larger or ventral valve.
b. Exterior of the upper (dorsal) valve. (Davidson, 'Palæontograph, Monog.')

Subsequent researches of M. Barrande have raised the number of cephalopods to 970 species and the Trilobites to nearly 400, while many of the other groups are almost doubled. So great is the number of cephalopods in this Silurian fauna of Bohemia that it might truly be characterised as the age of cephalopods.

Silurian strata of the United States.—The Silurian formations can be advantageously studied in the States of New York, Ohio, and other regions north and south of the great Canadian lakes. Here they are often found, as in Russia, nearly in horizontal position, and are more rich in well-preserved fossils than in almost any spot in Europe. In the State of New York, where the succession of the beds and their fossils have been most carefully worked out by the Government surveyors, the subdivisions given in the first column of the annexed list have been adopted.

Subdivisions of the Silurian Strata of New York. (Strata below the Oriskany Sandstone or base of the Devonian.)

New York Names	British Equivalents
1. Upper Pentamerus Limestone	Upper Silurian (or Ludlow and Wenlock Formations).
2. Encrinal Limestone	
Delthyris Shaly Limestone	
4. Pentamerus and Tentaculite Limestones	
5. Water Lime Group	
6. Onondaga Salt Group	
7. Niagara Group	
8. Clinton Group	Beds of Passage, Llandovery Group.
9. Medina Sandstone	
10. Oneida Conglomerate	
11. Grey Sandstone	
12. Hudson River Group	Lower Silurian (or Caradoc and Bala, Landeilo and Arenig Formations).
13. Trenton Limestone	
14. Black-River Limestone	
15. Bird's-Eye Limestone	
16. Chazy Limestone	
17. Calciferous Sandstone	

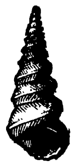
In the second column of the same table I have added the supposed British equivalents. All palæontologists, European and American, such as MM. de Verneuil, D. Sharpe, Prof. Hall, E. Billings, and others, who have entered upon this comparison, admit that there is a marked general correspondence in the succession of fossil forms, and even species, as we trace the organic remains downwards from the highest to the lowest beds ; but it is impossible to parallel each minor subdivision.

That the Niagara Limestone, over which the river of that name is precipitated at the great cataract, together with its underlying shales, corresponds to the Wenlock limestone and shale of England there can be no doubt. Among the species common to this formation in America and Europe are *Calymene Blumenbachii*, *Homalonotus delphinocephalus* (fig. 553, p. 465), with several other trilobites ; *Rhynchonella Wilsoni* (fig. 540, p. 459), and *Retzia cuneata ; Orthis elegantula*, *Pentamerus galeatus*, with many more brachiopods ; *Orthoceras annulatum*, among the cephalopodous shells ; and *Favosites Gothlandica*, with other large corals.

The Clinton Group, containing *Pentamerus oblongus* and *Stricklandinia*, and related more nearly by its fossil species with the beds above than with those below, is the equivalent of the Llandovery Group or beds of passage.

The Hudson River Group, and the Trenton Limestone, agree palæontologically with the Caradoc or Bala Group, containing in common with them several species of trilobites, such as *Asaphus* (*Isotelus*) *gigas*, *Trinucleus concentricus* (fig. 562, p. 470); and various shells, such as *Orthis striatula*, *Orthis biforata* (or *O. lynx*), *O. porcata* (*O. occidentalis* of Hall), and *Bellerophon bilobatus*. In the Trenton limestone occurs *Murchisonia gracilis* (fig. 576), a fossil also common to the Llandeilo beds in England.

Fig. 576.



Murchisonia gracilis, Hall.

A fossil characteristic of the Trenton L[illegible]. The genus is common in Lower Silurian rocks.

Mr. D. Sharpe, in his report on the mollusca collected by me from these strata in North America[1] concluded that the number of species common to the Silurian rocks on both sides of the Atlantic was between 30 and 40 per cent.; a result which, although no doubt liable to future modification, when a larger comparison shall have been made, proves, nevertheless, that many of the species had a wide geographical range. It seems that comparatively few of the gasteropods and lamellibranchiate bivalves of North America can be identified specifically with European fossils, while no less than two-fifths of the brachiopoda, of which my collection chiefly consisted, are the same. In explanation of these facts, it is suggested that most of the recent brachiopods (especially the orthidiform ones) are inhabitants of deep water, and that they may have had a wider geographical range than shells living near shore. The predominance of bivalve mollusca of this peculiar class has caused the Silurian period to be sometimes styled 'the age of brachiopods.'

In Canada, as in the State of New York, the Potsdam Sandstone underlies the above-mentioned calcareous rocks, but contains a different suite of fossils, as will be hereafter explained. In parts of the globe still more remote from Europe the Silurian strata have also been recognised, as in South America, Australia, and India. In all these regions the facies of the fauna, or the types of organic life, enable us to recognise the contemporaneous origin of the rocks; but the fossil species are distinct, showing that the old notion of a universal diffusion throughout the 'primæval seas' of one uniform specific fauna was quite unfounded, geographical provinces having evidently existed in the oldest as in the most modern times.

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[1] Quart. Geol. Journ., vol. vi.

CHAPTER XXVII.

CAMBRIAN AND LAURENTIAN GROUPS.

Classification of the Cambrian group, and its equivalent in Bohemia—Upper Cambrian rocks—Tremadoc slates and their fossils—Lingula Flags—Lower Cambrian rocks—Menevian Beds—Longmynd group—Harlech grits with large Trilobites—Llanberis slates—Cambrian rocks of Bohemia—Primordial zone of Barrande—Metamorphosis of Trilobites—Cambrian Rocks of Sweden and Norway—Cambrian Rocks of the United States and Canada—Potsdam sandstone—Huronian series—Laurentian group, upper and lower—*Eozoon Canadense*, oldest known fossil—Fundamental gneiss of Scotland.

CAMBRIAN GROUP.

THE characters of the Upper and Lower Silurian rocks were established so fully, both on stratigraphical and palæontological data, by Sir Roderick Murchison after five years' labour, in 1839, when his 'Silurian System' was published, that these formations could from that period be recognised and identified in all other parts of Europe and in North America, even in countries where most of the fossils differed specifically from those of the classical region in Britain, where they were first studied.

While Sir R. I. Murchison was exploring in 1833 in Shropshire and the borders of Wales the strata which in 1835 he first called Silurian, Professor Sedgwick was surveying the rocks of North Wales, which both these geologists considered at that period as of older date, and for which in 1836 Sedgwick proposed the name of 'Cambrian.' It was afterwards found that a large portion of the slaty rocks of North Wales which had been considered as more ancient than the Llandeilo beds and Stiper-Stones before alluded to, were, in reality, not inferior in position to those Lower Silurian beds of Murchison, but merely extensive undulations of the same, bearing fossils identical in species, though these were generally rarer and less perfectly preserved, owing to the changes which the rocks had undergone from metamorphic action. To such rocks the term 'Cambrian' was no longer applicable, although it continued to be appropriate to strata inferior to the Stiper-Stones, and which were older than those of the Lower Silurian group as originally defined. It was not till 1846 that fossils were found in Wales in the Lingula flags, the place of which will be seen in the annexed table. By this time Barrande had already published an account of a rich collection of fossils which he had discovered in Bohemia, portions of which he recognised as of corresponding age with Murchison's Upper and Lower Silurian, while others were more ancient, to which he gave the name of 'Primordial,' for the fossils were sufficiently distinct to entitle the rocks to be referred to a new and earlier period. They consisted chiefly of trilobites of genera distinct from those occurring in the overlying Silurian formations. These peculiar genera were afterwards found in rocks holding a corresponding position in Wales, and I shall retain for them the term Cambrian, as recent discoveries in our own country seem to carry the first fauna of Barrande, or his primordial type, even into older strata than any which he found to be fossiliferous in Bohemia.

The term primordial was intended to express M. Barrande's own belief that the fossils of the rocks so called afforded evidence of the first appearance of vital phenomena on this planet, and that consequently no fossiliferous strata of older date would or could ever be discovered. The acceptance of such a nomenclature would seem to imply that we despaired of extending our discoveries of new and more ancient fossil groups at some future day when vast portions of the globe, hitherto unexplored, should have been thoroughly surveyed. Already the discovery of the Laurentian Eozoon in Canada, presently to be mentioned, discountenances such views.

The following table will show the succession of the strata in England and Wales which belong to the Cambrian group, or the fossiliferous rocks older than the Arenig or Lower Llandeilo rocks.

UPPER CAMBRIAN.

TREMADOC SLATES. (*Primordial of Barrande in part.*)
LINGULA FLAGS. (*Primordial of Barrande.*)

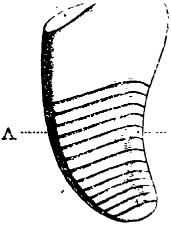
LOWER CAMBRIAN.

MENEVIAN BEDS. (*Primordial of Barrande.*)
LONGMYND GROUP { *a.* Harlech Grits.
b. Llanberis Slates.

UPPER CAMBRIAN.

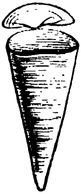
Tremadoc Slates.—The Tremadoc slates of Sedgwick are more than 1,000 feet in thickness, and consist of dark earthy slates occurring near the little town of Tremadoc, situated on the north side of Cardigan Bay in Carnarvonshire. These grey rocks and slates were first examined by Sedgwick in 1831, and were re-examined by him and described in 1846.[1] They were traced by their pisolitic ore from Tremadoc to Dolgelly, but no peculiar fossils were then observed in them, though some organic remains had been found in the underlying Lingula flags by Mr. Davis. 68 species of all classes have now, however, been found in the Tremadoc slates, thanks to the researches of Messrs. Salter, Homfray, Hicks, and Ash, and of these 60 are peculiar, only 4 passing up into higher strata, thus exhibiting a line of demarcation between the Silurian and Cambrian formations greater than any yet recognised in the Paleozoic series. We have already seen that in the Arenig or Stiper-stones group, where the species are distinct, the genera agree with Silurian types; but in these Tremadoc slates, where the species are also peculiar, there is about an equal admixture of Silurian types with those which Barrande has termed 'primordial.' Here, therefore, it may truly be said that we are entering upon a new domain of life in our retrospective survey of the past. The trilobites of new species, but of Lower Silurian genera, belong to *Ogygia*, *Asaphus*, and *Cheirurus*; whereas those belonging to primordial types, or Barrande's first fauna, as well as to the Lingula flags of Wales, comprise *Dikelocephalus*, *Conocoryphe* (for genera see figs. 587 and 591),[2] *Olenus*, and *Angelina*. The genus Bellerophon is represented in the Tremadoc slates by species different to those found in the Lower Silurian: the Pteropods *Theca* (fig. 578), and *Conularia* range throughout these slates, but there are no Graptolites. The *Lingula* (*Lingulella*) *Davisii* ranges from the top to the bottom of the formation, and links it with the zone next to be described. The Tremadoc

Fig. 5



Cyrtoceras precox, Salt.
Llandeilo and Tremadoc rocks, N. Wales.
a. Dorsal edge, place of siphuncle.
b. Aperture. *c.* Ventral edge.

Fig. 578.



Theca (*Cleidotheca*) *operculata*.
Lower Tremadoc beds,
Tremadoc.

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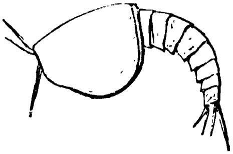
[1] Geol. Quart. Journ., vol. iii. p. 156.

[2] This genus has been substituted for Barrande's *Conocephalus*, as the latter term had been preoccupied by the entomologists.

beds were formerly supposed to be confined to a small part of North Wales, but more lately beds of the same age have been discovered and thoroughly investigated by Dr. Hicks at St. David's promontory and Ramsey Island, South Wales. He states that they rest conformably on the Lingula flags, and usually graduate by insensible degrees into them.[1] 12 species of Lamellibranchiata occur in the Tremadoc beds of Ramsey Island, and this is at present the earliest formation in which they are found. Two genera, *Glyptarca* and *Davidia,* are new. The Echinoderms are represented by a beautiful star-fish of the genus *Palasterina* and by an Encrinite of the genus *Dendrocrinus.*[2] Cephalopoda have not yet been found lower than this group, and only two peculiar species, *Cyrtoceras precox* (fig. 577) and *Orthoceras sericeum*, are known here.

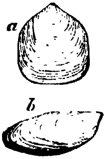
Lingula Flags.—Next below the Tremadoc slates in North Wales, lie micaceous flagstones and slates, in which in 1846, Mr. E. Davis discovered the *Lingula* (*Lingulella*) (fig. 580) named after him, and from which was derived the name of Lingula flags. These beds, which are paleontologically the equivalents of Barrande's primordial zone, are represented by more than 5,000 feet of strata, and have been studied chiefly in the neighbourhood of Dolgelly, Ffestiniog, and Portmadoc in North Wales, and also at St. David's in South Wales. They have yielded about 35 species of fossils, of which six only are common to the overlying Tremadoc rocks, but the two formations are closely allied by having several characteristic 'primordial' genera in common. *Dikelocephalus*, *Paradoxides*, *Olenus* (fig. 581), and *Conocoryphe* are prominent forms, as is also *Hymenocaris* (fig. 579), a genus of phyllopod crustacean entirely confined to the Lingula Flags. According to Mr. Belt, who has devoted much

Fig. 579.



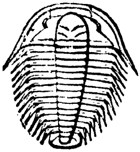
Hymenocaris vermicauda,
Salter.
A Phyllopod Crustacean.
½ natural size.

Fig. 580.



Lingulella Davisii,
M'Coy.
a. ½ natural size.
b. Distorted by cleavage.

Fig. 581.



Olenus micrurus,
Salter.
½ natural size.

'Lingula Flags' of Dolgelly, and Ffestiniog; N. Wale attention to these beds, there are already paleontological data for subdividing the Lingula Flags into three sections,[1] the Dolgelly, Ffestiniog, and Maentwrog groups.

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[1] Hicks, Proc. of Geol. Assoc., vol. iii. No. 3., 1873.

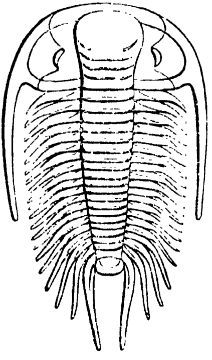
[2] Hicks, Quart. Geol. Journ., vol. xxix. p. 42.

In Merionethshire, according to Professor Ramsay, the Lingula Flags attain their greatest development; in Carnarvonshire, they thin out so as to have lost two-thirds of their thickness in eleven miles, while in Anglesea and on the Menai Straits both they and the Tremadoc beds are entirely absent, and the Lower Silurian rests directly on Lower Cambrian strata.

LOWER CAMBRIAN.

Menevian Beds.—Immediately beneath the Lingula Flags there occurs a series of dark grey and black flags and slates alternating at the upper part with some beds of sandstone, the whole reaching a thickness of from 500 to 600 feet. These beds were formerly classed, on purely lithological grounds, as the base of the Lingula Flags, but Messrs. Belt, Hicks, and Salter,[2] to whose exertions we owe almost all our knowledge of the fossils, have pointed out, that the most characteristic genera found in them are quite unknown in the Lingula Flags, while they possess many genera, such as *Microdiscus* and *Paradoxides*, characteristic of the underlying Longmynd Group. They therefore proposed to place them, and it seems to me with good reason, at the top of the Lower Cambrian under the term 'Menevian,' Menevia being the classical name of St. David's. The beds are well exhibited in the neighbourhood of St. David's in South Wales, and near Dolgelly and Maentwrog in North Wales. They are the equivalents of Étage C of Barrande's Primordial Zone. 52 species have been found in them, and the group is altogether very rich in fossils common to the overlying Lingula Flags, but none pass up to the Tremadoc beds. The trilobites are of large size; *Paradoxides Davidis* (see fig. 582), the largest trilobite known in Great Britain, 22 inches or nearly 2 feet long, is peculiar to the

Fig. 582.



Paradoxides Davidis, Salt.
1/10 nat. size.
Menevian beds,
St. David's and Dolgelly.

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[1] Geol. Mag., vols. iv. and v., 1867 and 1868.

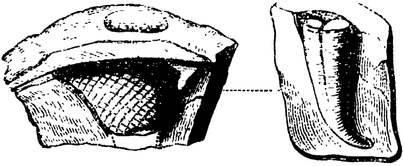
[2] British Association Report, 1865, 1866, 1868, and Quart. Geol. Journ., vols. xxi. xxv.

Menevian beds. By referring to the Bohemian trilobite of the same genus (fig. 586, p. 487), the reader will at once see how these fossils (though of such different dimensions) resemble each other in Bohemia and Wales, and other closely allied species from the two regions might be added, besides some which are common to both countries. The Swedish fauna, presently to be mentioned, will be found to be still more nearly connected with the Welsh Menevian. In all these countries there is an equally marked difference between the Cambrian fossils and those of the Upper and Lower Silurian rocks. The trilobite with the largest number of rings, *Erinnys venulosa*, occurs here in conjunction with *Agnostus* and *Microdiscus*, the two genera with the smallest number. Blind trilobites are also found as well as those which have the largest eyes, such as *Microdiscus* on the one hand, and *Anopolenus* on the other.

LONGMYND GROUP.

Older than the Menevian Beds, are a thick series of olive green, purple, red and grey grits and conglomerates found in North and South Wales, Shropshire, and parts of Ireland and Scotland. They have been called by Professor Sedgwick the Longmynd or Bangor Group, comprising, first, the Harlech and Barmouth sandstones ; and secondly, the Llanberis slates.

Harlech grits and Llanberis slates.—The sandstones of this period attain in the Longmynd hills a thickness of no less than 6,000 feet without any interposition of volcanic matter ; in some places in Merionethshire they are still thicker. Until recently these rocks possessed but a very scanty fauna.



Histioderma Hibernica (Kin.). Oldhamia beds. Bray Head, Ireland.

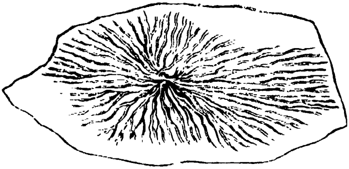
1. Showing opening of burrow, and tube with wrinklings or crossing ridges, probably produced by a tentacled sea worm or annelid.
2. Lower and curved extremity of tube with five transverse lines.

With the exception of five species of annelids brought to light by Mr. Salter in Shropshire, and Dr. Kinahan in Wicklow, and an obscure form of trilobite. *Palæopyge Ram-*

sayi, they were supposed to be barren of organic remains. Now, however, through the labours of Mr. Hicks,[1] they have yielded at St. David's a rich fauna of trilobites, brachiopods, phyllopods, and pteropods, showing together with other fossils, a by no means low series of organisms at this early period. Already the fauna amounts to 25 species referred to 17 genera; of these 12 genera and 8 species are common to the Menevian Group, 'a proportion,' says Mr. Hicks, 'far greater than we usually find between two groups so dissimilar in lithological characters and comprising so great a thickness of strata.

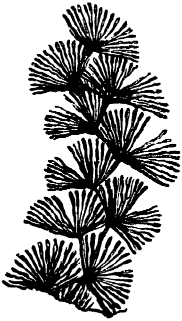
A new genus of trilobite, called *Plutonia Sedgwickii* by Dr. Hicks, has been met with in the Harlech grits of St. David's.

Fig. 584.



Oldhamia radiata, Forbes. Wicklow, Ireland.

Fig. 585.



Oldhamia antiqua, Forbes. Wicklow, Ireland.

It is comparable in size to the large *Parodoxides Davidis* before mentioned, has well-developed eyes, and is covered all over with rough tubercles. In the same strata occur other genera of trilobites, namely, *Conocoryphe*, *Paradoxides*, *Microdiscus*, and the Pteropod *Theca* (fig. 578), all represented by species peculiar to the Harlech grits of that area. The sandstones of this formation are often rippled, and were evidently left dry at low tides, so that the surface was dried by the sun and made to shrink and present sun-cracks. There are also distinct impressions of raindrops on many surfaces, like those figured at p. 409. Fossils occur yet earlier in the Harlech group of St. David's in the lower Red Shales that immediately overlie the conglomerate and hornstone series. The only forms yet found are *Lingulella ferruginea*, *L. primæva*, and *Leperditia primæva*, and these constitute the earliest life (with the exception of Eozoon, presently to be mentioned) yet met with. The succeeding 1,500 feet of greenish yellow and green-and-red sandstones have yielded no organic remains.

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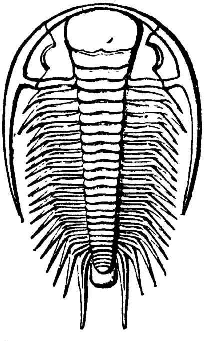
[1] Brit. Assoc. Report, 1868.

The slates of Llanberis and Penrhyn in Carnarvonshire, with their associated sandy strata, attain a great thickness, sometimes about 3,000 feet. They are perhaps not more ancient than the Harlech and Barmouth beds last mentioned, for they may represent the deposits of fine mud thrown down in the same sea, on the borders of which the sands above mentioned were accumulating. In some of these slaty rocks at Bray Head in Ireland, immediately opposite Anglesea and Carnarvon, two species of fossils have been found, to which the late Professor E. Forbes gave the name of *Oldhamia*. The nature of these organisms is still a matter of discussion among naturalists.

Cambrian rocks of Bohemia (*Primordial zone of Barrande*).—We have already seen when treating of the Silurian strata of Bohemia, p. 447, that in the year 1846 Barrande gave the name of Étage C to the earliest fauna discovered by him in that country.

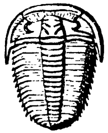
Fossils of the lowest Fossiliferous Beds in Bohemia, or 'Primordial Zone' of Barrande.

Fig. 586.



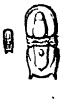
Paradoxides Bohemicus, Barr.
About ½ natural size.

Fig. 587.



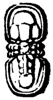
Conocoryphe striata, Syn.
Conocephalus striatus, Emmrich.
½ natural size. Ginetz and Skrey.

Fig. 588.



Agnostus integer, Beyrich.
Nat. size and magnified.

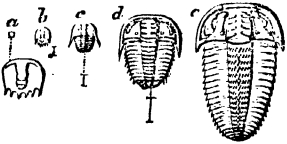
Fig. 589.



Agnostus Rex, Barr.
Nat. size, Skrey.

This Étage C or primordial zone is now proved to be the equivalent of those subdivisions of the Cambrian groups which have been above described under the names of Menevian and Lingula Flags. In it M. Barrande found in Bohemia trilobites of the genera *Paradoxides, Conocoryphe, Ellipsocephalus, Sao, Arionellus, Hydrocephalus*, and *Agnostus*. M. Barrande pointed out that these primordial trilobites have a peculiar facies of their own, dependent on the multiplication of their thoracic segments and the diminution of their caudal shield or pygidium.

Fig. 590.



The small lines beneath indicate the true size. In the youngest state, *a*, no segments are visible; as the metamorphosis progresses, *b*, *c*, the body segments begin to be developed; in the stage *d* the eyes are introduced, but the facial sutures are not completed; at *e* the full-grown animal, half its true size, is shown.

Sao hirsuta, Barrande, in its various stages of growth.

One of the 'primordial' or Upper Cambrian Trilobites of the genus *Sao*, a form not found as yet elsewhere in the world, afforded M. Barrande a fine illustration of the metamorphosis of these creatures, for he traced them through no less than twenty stages of their development. A few of these changes have been selected for representation in the accompanying figures, that the reader may learn the gradual manner in which different segments of the body and the eyes make their appearance.

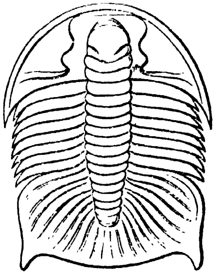
In Bohemia the primordial fauna of Barrande derived its importance exclusively from its numerous and peculiar trilobites. Besides these, however, the same ancient schists have yielded two genera of brachiopods, *Orthis* and *Orbicula*, a pteropod of the genus *Theca*, and four echinoderms of the Cystidean family.

Cambrian of Sweden and Norway.—The Cambrian beds of Wales are represented in Sweden by strata, the fossils of which have been described by a most able naturalist, M. Angelin, in his 'Palæontologica Suecica (1852–4).' The 'alum-schists,' as they are called in Sweden, are horizontal argillaceous rocks which underlie conformably certain Lower Silurian strata in the mountain called Kinnekulle, south of the great Wener Lake in Sweden. These schists contain trilobites belonging to the genera *Paradoxides*, *Olenus*, *Agnostus*, and others, some of which present rudimentary forms, like the genus last mentioned, without eyes, and with the body segments scarcely developed, and others again have the number of segments excessively multiplied, as in *Paradoxides*. Such peculiarities agree with the characters of the crustaceans met with in the Cambrian strata of Wales, and Dr. Torell has recently found in Sweden the *Paradoxides Hicksii*, a well-known Lower Cambrian fossil.

At the base of the Cambrian strata in Sweden, which in the neighbourhood of Lake Wener are perfectly horizontal, lie ripple-marked quartzose sandstones with worm tracks and annelid borings, like some of those found in the Harlech grits of the Longmynd. Among these are some which have been referred doubtfully to plants. These sandstones have been called in Sweden 'fucoid sandstones.' The whole thickness of the Cambrian rocks of Sweden does not exceed 300 feet from the equivalents of the Tremadoc beds to these sandstones, which last seem to correspond with the Longmynd and are regarded by Torell as older than any fossiliferous primordial rocks in Bohemia.

Cambrian of the United States and Canada (*Potsdam Sandstone*).—This formation, as we learn from Sir W. Logan, is 700 feet thick in Canada ; the upper part consists of sandstone containing fucoids, and perforated by small vertical holes, which are very characteristic of the rock, and appear to have been made by annelids (*Scolithus linearis*). The lower portion is a conglomerate with quartz pebbles. I have seen the Potsdam sandstone on the banks of the St. Lawrence, and on the borders of Lake Champlain, where, as at Keesville, it is a white quartzose fine-grained grit, almost passing into quartzite. It is divided into horizontal ripple-marked beds, very like those of the Lingula Flags of Britain, and replete with a small round-shaped *Obolella*, in such numbers as to divide the rock into parallel planes, in the same manner as do the scales of mica in some micaceous sandstones. Among the shells of this formation in Wisconsin are species of *Lingula* and *Orthis*, and several trilobites of the primordial genus *Dikelocephalus* (fig. 591). On the banks of the St. Lawrence, near Beauharnois and elsewhere, many fossil footprints have been observed on the surface of the rippled layers. They are supposed by Professor Owen to be the trails of more than one species of articulate animal, probably allied to the King Crab, or *Limulus*.

Fig. 591.



Dikelocephalus Minnesotensis, Dale Owen. ⅓ diameter.
A large crustacean of the Olenoid group. Potsdam Sandstone. Falls of St. Croix, on the upper Mississippi.

Recent investigations by the naturalists of the Canadian survey have rendered it certain that below the level of the Potsdam Sandstone there are slates and schists extending from New York to Newfoundland, occupied by a series of trilobitic forms similar in genera though not in species to those found in the European Upper Cambrian strata.

Huronian series.—Next below the Upper Cambrian occur strata called the Huronian by Sir W. Logan, which are of vast thickness, consisting chiefly of a quartzite, with great masses of greenish chloritic slate, which sometimes include pebbles of crystalline rocks derived from the Laurentian formation, next to be described. Limestones are rare in this series, but one band of 300 feet in thickness has been traced for considerable distances to the North of Lake Huron. Beds of greenstone are intercalated conformably with the quartzose and argillaceous members of this series. No organic remains have yet been found in any of the beds, which are about 18,000 feet thick, and rest unconformably on the Laurentian rocks.

LAURENTIAN GROUP.

In the course of the geological survey carried on under the direction of Sir W. E. Logan, it has been shown that, northward of the river St. Lawrence, there is a vast series of crystalline rocks of gneiss, mica-schist, quartzite, and limestone, more than 30,000 feet in thickness, which have been called Laurentian, and which are already known to occupy an area of about 200,000 square miles. They are not only more ancient than the fossiliferous Cambrian formations above described, but are older than the Huronian last mentioned, and had undergone great disturbing movements before the Potsdam sandstone and the other 'primordial' or Cambrian rocks were formed. The older half of the Laurentian series is unconformable to the newer portion of the same.

Upper Laurentian or Labrador series.—The Upper Group, more than 10,000 feet thick, consists of stratified crystalline rocks in which no organic remains have yet been found. They consist in great part of felspars, which vary in composition from anorthite to andesine, or from those kinds in which there is less than one per cent. of potash and soda to those in which there is more than seven per cent. of these alkalies, the soda preponderating greatly. These felsparites sometimes form mountain masses almost without any admixture of other minerals; but at other times they include augite, which passes into hypersthene. They are often granitoid in structure. One of the varieties is the same as the iridescent labradorite rock of Labrador. The Adirondack Mountains in the State of New York are referred to the same series, and it is conjectured that the hypersthene rocks of Skye, which resemble this formation in mineral character, may be of the same geological age.

Lower Laurentian.—This series, about 20,000 feet in thickness, is, as before stated, unconformable to that last mentioned;

it consists in great part of gneiss of a reddish tint with orthoclase felspar. Beds of nearly pure quartz, from 400 to 600 feet thick, occur in some places. Hornblendic and micaceous schists are often interstratified, and beds of limestone usually crystalline. Beds of plumbago also occur, and it has naturally been conjectured that this pure carbon may have been of organic origin before it underwent metamorphism.

There are several of these limestones which have been traced to great distances, and one of them is from 700 to 1,500 feet thick. In the most massive of them Sir W. Logan observed in 1859 what he considered to be an organic body much resembling the Silurian fossil called *Stromatopora rugosa*. It had been obtained the year before by Mr. J. McCulloch at the Grand Calumet on the river Ottawa. This fossil was examined in 1864 by Dr. Dawson of Montreal, who detected in it, by aid of the microscope, the distinct structure of a Rhizopod or Foraminifer. Dr. Carpenter and Prof. T. Rupert Jones have since confirmed this opinion, comparing the structure to that of the well-known nummulite. It appears to have grown one layer over another, and to have formed reefs of limestone as do the living coral-building polyp animals. Parts of the original skeleton, consisting of carbonate of lime, are still preserved ; while certain interspaces in the calcareous fossil have been filled up with serpentine and white augite. On this oldest of known organic remains Dr. Dawson has conferred the name of *Eozoon Canadense* (see figs. 592, 593) ; its antiquity is such that the dis-

Fig. 592.

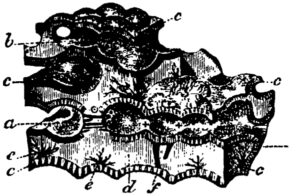
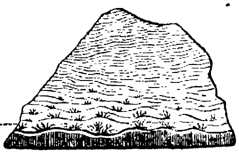


Fig. 593.



Eozoon Canadense, Daw. (after Carpenter). Oldest known organic body.

Fig. 592. *a*. Chambers of lower tier communicating at +, and separated from adjoining chambers at ⊙ by an intervening septum, traversed by passages. *b*. Chambers of an upper tier. *c*. Walls of the chambers, traversed by fine tubules. (These tubules pass with uniform parallelism from the inner to the outer surface, opening at regular distances from each other.) *d*. Intermediate skeleton, composed of homogeneous shell substance, traversed by stoloniferous passages (*f*), connecting the chambers of the two tiers. *e*. Canal system in intermediate skeleton, showing the arborescent sarcodic prolongations. (Fig. 593 shows these bodies in a decalcified state.) *f*. Stoloniferous passages.

Fig. 593. Decalcified portion of natural rock, showing *canal system* and the several layers ; the acuteness of the planes prevents more than one or two parallel tiers being observed. Natural size.

tance of time which separated it from the Upper Cambrian period, or that of the Potsdam sandstone, may, says Sir W. Logan, be equal to the time which elapsed between the Potsdam sandstone and the nummulitic limestones of the Tertiary period. The Laurentian and Huronian rocks united are about 50,000 feet in thickness, and the Lower Laurentian was disturbed before the newer series was deposited. We may naturally expect that other proofs of unconformability will hereafter be detected at more than one point in so vast a succession of strata.

The mineral character of the Upper Laurentian differs, as we have seen, from that of the Lower, and the pebbles of gneiss in the Huronian conglomerates are thought to prove that the Laurentian strata were already in a metamorphic state before they were broken up to supply materials for the Huronian. Even if we had not discovered the Eozoon, we might fairly have inferred from analogy that as the quartzites were once beds of sand, and the gneiss and mica-schist derived from shales and argillaceous sandstones, so the calcareous masses from 400 to 1,000 feet and more in thickness, were originally of organic origin. This is now generally believed to have been the case with the Silurian, Devonian, Carboniferous, Oolitic, and Cretaceous limestones and those nummulitic rocks of tertiary date which bear the closest affinity to the Eozoon reefs of the Lower Laurentian. The oldest stratified rock in Scotland is that called by Sir R. Murchison 'the fundamental gneiss,' which is found in the north-west of Ross-shire, and in Sutherlandshire (see fig. 82, p. 89), and forms the whole of the adjoining island of Lewis, in the Hebrides. It has a strike from north-west to south-east, nearly at right angles to the metamorphic strata of the Grampians. On this Laurentian gneiss, in parts of the Western Highlands, the Lower Cambrian and various metamorphic rocks rest unconformably. It seems highly probable that this ancient gneiss of Scotland may correspond in date with part of the great Laurentian group of North America.

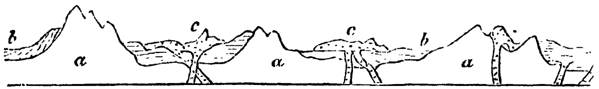
CHAPTER XXVIII.

VOLCANIC ROCKS.

External form, structure, and origin of volcanic mountains—Cones and craters—Hypothesis of 'elevation craters' considered—Trap rocks—Name whence derived—Minerals most abundant in volcanic rocks—Table of the analysis of minerals in the Volcanic and Hypogene rocks—Similar minerals in meteorites—Theory of Isomorphism—Basaltic rocks—Trachytic rocks—Special forms of structure—The columnar and globular forms—Trap dikes and veins—Alteration of rocks by volcanic dikes—Conversion of chalk into marble—Intrusion of trap between strata—Relation of trappean rocks to the products of active volcanos.

The aqueous or fossiliferous rocks having now been described, we have next to examine those which may be called volcanic, in the most extended sense of that term. Suppose *a a* in the annexed diagram to represent the crystalline formations, such as the granitic and metamorphic; *b b* the fossiliferous strata; and *c c* the volcanic rocks. These last are sometimes found, as was explained in the first chapter, breaking through *a* and *b*, sometimes overlying both, and occasionally alternating with the strata *b b*.

Fig. 594.

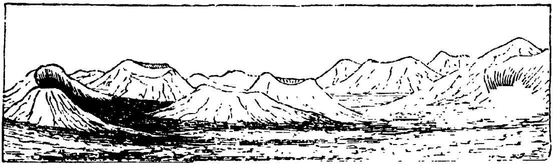


a. Hypogene formations, stratified and unstratified.
b. Aqueous formations. *c*. Volcanic rocks.

External form, structure, and origin of volcanic mountains.—The origin of volcanic cones with crater-shaped summits has been explained in the 'Principles of Geology' (chaps. xxiii. to xxvii.), where Vesuvius, Etna, Santorin, and Barren Island are described. The more ancient portions of those mountains or islands, formed long before the times of history, exhibit the same external features and internal structure which belong to most of the extinct volcanos of still higher antiquity; and these last have evidently been due to a complicated series of operations, varied in kind according to circumstances; as, for example, whether the accumulation took place above or below the level of the sea, whether the lava issued from one or several contiguous vents, and, lastly, whether the products of fusion in the subterranean regions contain more or less silica, alumina, potash, soda, lime, oxides of iron, and other ingredients. We are best acquainted with the effects of eruptions above water, or those called subaërial or supramarine; yet the products even of these are arranged in so many ways that their interpretation has given rise to a variety of contradictory opinions, some of which will have to be considered in this chapter.

Cones and Craters.—In regions where the eruption of volcanic matter has taken place in the open air, and where the surface has never since been subjected to great aqueous denudation, cones and craters constitute the most striking peculiarity of this class of formations. Many hundreds of these cones are seen in central France, in the ancient provinces of Auvergne, Velay, and Vivarais, where they observe, for the most part, a linear arrangement, and form chains of hills. Although none of the eruptions have happened within the historical era, the streams of lava may still be traced distinctly descending from many of the craters, and following the lowest levels of the existing valleys. The origin of the cone and crater-shaped hill is well understood, the growth of many having been watched during volcanic eruptions. A chasm or fissure first opens in the earth, from which great volumes of steam are evolved. The explosions are so violent as to splinter the rocks in which the volcanic vent is opened, and hurl up into the air fragments of broken stone, parts of which are shivered into minute atoms. At the same time liquefied stone or *lava* usually ascends through the chimney or vent by which the gases make their escape. Although extremely heavy, this lava is forced up by the expansive power of entangled gaseous fluids, chiefly steam or aqueous vapour, exactly in the same manner as water is made to boil over the edge of a vessel when steam has been generated at the bottom by heat. Large quantities of the lava are also shot up into the air, where it separates into fragments and acquires a spongy texture by the sudden enlargement of the included gases, and thus forms *scoriæ*, other portions being reduced to an impalpable powder, or dust. The showering down of the various ejected materials round the orifice of eruption gives rise to a conical mound, in which the successive envelopes of sand and scoriæ form layers, dipping on all sides from a central axis. In the mean time a hollow, called a *crater*, has been kept open in the middle of the mound by the continued passage upwards of steam and other gaseous fluids. The lava sometimes flows over the edge of the crater, and thus thickens and strengthens the sides of the cone; but sometimes it breaks down the cone on one side (see fig. 595), and often it flows out from a fissure at the base of the hill, or at some distance from its base.

Fig. 595.



Part of the chain of extinct volcanos called the Monts Dome, Auvergne. (Scrope.)

Some geologists had erroneously supposed from observations made on recent cones of eruption, that lava which consolidates on steep slopes is always of a scoriaceous or vesicular structure, and never of that compact texture which we find in those rocks which are usually termed 'trappean.' Misled by this theory, they have gone so far as to believe that if melted matter has originally descended a slope at an angle exceeding four or five degrees, it never on cooling acquires a stony compact texture. Consequently, whenever they found in a volcanic mountain sheets of stony materials inclined at angles of from 5° to 20° or even more than 30°, they thought themselves warranted in assuming that such rocks had been originally horizontal, or very slightly inclined, and had acquired their high inclination by subsequent upheaval. To such dome-shaped mountains with a cavity in the middle, and with the inclined beds having what was called a quâquâversal dip or a slope outwards on all sides, they gave the name of 'Elevation craters.'

As the late Leopold von Buch, the author of this theory, had selected the Isle of Palma, one of the Canaries, as a typical illustration of this form of volcanic mountain, I visited that island in 1854, in company with my friend Mr. Hartung, and I satisfied myself that it owes its origin to a series of eruptions of the same nature as those which formed the minor cones, already alluded to. In some of the more ancient or Miocene volcanic mountains, such as Mont Dore and Cantal in Central France, the mode of origin by upheaval as above described is attributed to those dome-shaped masses, whether they possess or not a great central cavity as in Palma. Where this cavity is present, it has probably been due to one or more great explosions similar to that which destroyed a great part of ancient Vesuvius in the time of Pliny. Similar paroxysmal catastrophes have caused in historical times the truncation on a grand scale of some large cones in Java and elsewhere.[1]

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[1] Principles, vol. ii. pp. 56 and 145.

Among the objections which may be considered as fatal to von Buch's doctrine of upheaval in these cases I may state that a series of volcanic formations, extending over an area six or seven miles in its shortest diameter, as in Palma, could not be accumulated in the form of lavas, tuffs, and volcanic breccias or agglomerates without producing a mountain as lofty as that which they now constitute. But assuming that they were first horizontal, and then lifted up by a force acting most powerfully in the centre and tilting the beds on all sides, a central crater having been formed by explosion or by a chasm opening in the middle, where the continuity of the rocks was interrupted, we should have a right to expect that the chief ravines or valleys would open towards the central cavity, instead of which the rim of the great crater in Palma and other similar ancient volcanos is entire for more than three parts of the whole circumference.

If dikes are seen in the precipices surrounding such craters or central cavities, they certainly imply rents which were filled up with liquid matter. But none of the dislocations producing such rents can have belonged to the supposed period of terminal and paroxysmal upheaval, for had a great central crater been already formed before they originated, or at the time when they took place, the melted matter, instead of filling the narrow vents, would have flowed down into the bottom of the cavity, and would have obliterated it to a certain extent. Making due allowance for the quantity of matter removed by subaërial denudation in volcanic mountains of high antiquity, and for the grand explosions which are known to have caused truncation in active volcanos, there is no reason for calling in the violent hypothesis of elevation craters to explain the structure of such mountains as Teneriffe, the Grand Canary, Palma, or those of Central France, Etna, or Vesuvius, all of which I have examined. With regard to Etna, I have shown, from observations made by me in 1857, that modern lavas, several of them of known date, have formed continuous beds of compact stone even on slopes of 15, 36, and 38 degrees, and, in the case of the lava of 1852, more than 40 degrees. The thickness of these tabular layers varies from 1½ foot to 26 feet. At the same time the relations of these lava-streams to the surrounding rocks, and of their scoriaceous and compact portions to one another, are such as to preclude the possibility of a change of inclination having taken place subsequently to their solidification.[1]

Nomenclature of Trappean rocks.—When geologists first began to examine attentively the structure of the northern and western parts of Europe, they were almost entirely ignorant of the phenomena of existing volcanos. They found certain rocks, for the most part without stratification, and of a peculiar mineral composition, to which they gave different names, such as basalt, greenstone, porphyry, trap tuff, and amygdaloid. All these, which were recognised as belonging to one family, were called 'trap' by Bergmann, from *trappa*, Swedish for a flight of steps —a name since adopted very generally into the nomenclature of the science ; for it was observed that many rocks of this class occurred in great tabular masses of unequal extent, so as to form a succession of terraces or steps.

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[1] Memoir on Mount Etna, Phil. Trans., 1858.

By degrees familiarity with the products of active volcanos convinced geologists more and more that they were identical with the trappean rocks. In every stream of modern lava there is some variation in character and composition, and even where no important difference can be recognised in the proportions of silica, alumina, lime, potash, iron, and other elementary materials, the resulting minerals are often not the same, for reasons which we are as yet unable to explain. The difference also of the lavas poured out from the same mountain at two distinct periods, especially in the quantity of silica which they contain, is often so great as to give rise to rocks which are regarded as forming distinct families, although there may be every intermediate gradation between the two extremes, and although some rocks, forming a transition from the one class to the other, may often be so abundant as to demand special names. Rocks containing an excess of silica (from 60 to 80 per cent.) are termed by many petrologists *acid* rocks, while those which on the contrary contain a small proportion of silica (from 45 to 55 per cent.) and a large proportion of the bases lime, potash, magnesia, oxide of iron, &c., are termed *basic*. I do not, however, adopt these terms, as they are founded on distinctions about which chemists are not agreed, and the term *acid* has unfortunately a meaning quite different to the technical one proposed, while on the other hand the terms trachytic (as synonymous with acid) and basaltic (as synonymous with basic) appear to me to answer all practical purposes and to be far more intelligible to the ordinary student. The different species of rocks included under these two heads might be multiplied indefinitely, and I can only afford space to name a few of the principal ones, about the composition and aspect of which there is the least discordance of opinion.

Minerals most abundant in volcanic rocks.—The minerals which form the chief constituents of these igneous rocks are few in number. Next to quartz, which is nearly pure silica or silicic acid, the most important are those silicates commonly classed

Analysis of Minerals most abundant in the Volcanic and Hypogene Rocks.

	Silica	Alumina	Sesquioxide of Iron	Protoxides of Iron and Manganese	Lime	Magnesia	Potash	Soda	Other Constituents	Specific Gravity
THE QUARTZ GROUP.										
QUARTZ	100·0	...	...	...	...	...	...	...	...	2·6
TRIDYMITE	100·0	...	...	...	...	...	...	...	...	2·3
THE FELSPAR GROUP.										
ORTHOCLASE. Carlsbad, in granite (Bulk).	65·23	18·26	0·27	...	trace	...	14·66	1·45	...	2·55
—— Sanidine, Drachenfels in trachyte (Rammelsberg).	65·87	18·53	...	...	0·95	0·39	10·32	3·42	W. 0·44	
ALBITE. Arendal, in granite (G. Rose)	68·46	19·30	...	0·28	0·68		...	11·27	...	2·61
OLIGOCLASE. Ytterby, in granite (Berzelius).	61·55	23·80	...	...	3·18	0·80	0·38	9·67	...	2·65
—— Teneriffe, in trachyte (Deville)	61·55	22·03	...	...	2·81	0·47	3·44	7·74	...	2·59
LABRADORITE. Hitteroe, in Labrador-Rock (Waage).	51·39	29·42	2·90	...	9·44	0·37	1·10	5·63	W. 0·71	2·72
—— Iceland, in volcanic (Damour)	52·17	29·22	1·90	...	13·11	...	...	8·40	...	2·71
ANORTHITE. Harzburg, in diorite (Streng).	45·57	34·81	0·59	...	16·52	0·83	0·40	1·45	W. 0·87	2·74
—— Hecla, in volcanic (Waltershausen)	45·14	32·10	2·03	0·78	18·32	...	0·22	1·06	...	
LEUCITE. Vesuvius, 1811, in lava (Rammelsberg).	56·10	23·22	...	...	...	...	20·59	0·57	...	2·48
NEPHELINE. Miask, in miascite (Scheerer).	44·30	33·25	0·82	...	0·32	0·07	5·82	16·02	...	2·59
—— Vesuvius, in volcanic (Arfvedson)	44·11	33·73	...	...	...	...	...	20·46	W. 0·62	2·60
THE MICA GROUP.										
MUSCOVITE. Finland, in granite (Rose)	46·36	36·80	4·53	...	...	...	9·22	...	F. 0·67 W. 1·84	2·90
LEPIDOLITE, Cornwall, in granite (Regnault).	52·40	26·80	...	1·50	...	...	9·14	...	F. 4·18 Li. 4·85	2·90
BIOTITE. Bodenmais (V. Kobell)	40·86	15·13	13·00	...	...	22·00	8·83	...	W. 0·44	2·70
—— Vesuvius, in volcanic (Chodnef)	40·91	17·71	11·02	...	0·30	19·04	9·96	...	...	2·75
PHLOGOPITE. New York, in metam. limestone (Rammelsberg).	41·96	13·47	...	2·67	0·31	27·12	9·37	...	F. 2·93 W. 0·60	2·81
MARGARITE. Naxos (Smith)	30·02	49·52	1·65	...	10·82	0·48	1·25		W. 5·55	2·99
CHLORITE. Dauphiny (Marignac)	26·88	17·52	29·76	...	...	13·84	...	...	W. 11·33	2·87
RIPIDOLITE. Pyrenees (Delesse)	32·10	18·50	...	0·06	...	36·70	...	...	W. 12·10	2·61
TALC. Zillerthal (Delesse)	63·00	...	...	trace	...	33·60	...	...	W. 3·40	2·68
THE AMPHIBOLE AND PYROXENE GROUP.										
TREMOLITE. St. Gothard (Rammelsberg).	58·55	...	...	...	13·90	26·63	...	...	F.W. 0·34	2·93
ACTINOLITE. Arendal, in granite (Rammelsberg).	56·77	0·97	...	5·88	13·56	21·48	...	...	W. 2·20	3·02
HORNBLENDE. Faymont, in diorite (Deville).	41·99	11·66	...	22·22	9·55	12·59	...	1·02	W. 1·47	3·20
—— Etna, in volcanic (Waltershausen)	40·91	13·68	...	17·49	13·44	13·19	...	...	W. 0·85	3·21
URALITE. Ural (Rammelsberg)	50·75	5·65	...	17·27	11·59	12·28	...	...	W. 1·80	3·14
AUGITE. Bohemia, in dolerite (Rammelsberg).	51·12	3·38	0·95	8·06	23·54	12·82	...	...	...	3·36
—— Vesuvius, in lava of 1858 (Rammelsberg).	49·61	4·42	...	9·08	22·83	14·22	...	...	...	3·25
DIALLAGE. Harz, in Gabbro (Rammelsberg).	52·00	3·10	...	9·36	16·29	18·51	...	...	W. 1·10	3·23
HYPERSTHENE. Labrador, in Labrador-Rock (Damour).	51·36	0·37	...	22·59	3·09	21·31	...	...	...	3·39
BRONZITE. Greenland (V. Kobell)	58·00	1·33	11·14	...	...	29·66	...	...	...	3·20
OLIVINE. Carlsbad, in basalt (Rammelsberg).	39·34	...	...	14·85	...	45·81	...	...	...	3·40
—— Mount Somma, in volcanic (Walmstedt.)	40·08	0·18	...	15·74	...	44·22	...	...	...	3·33

In the last column but one of the above table the following signs are used: F. Fluorine; Li. Lithia W. Loss on igniting the mineral, in most instances only Water.

under the several heads of felspar, mica, hornblende or augite, and olivine. In the annexed table, in drawing up which I have received the able assistance of Mr. David Forbes, the chemical analysis of these minerals and their varieties is shown, and he has added the specific gravity of the different mineral species, the geological application of which in determining the rocks formed by these minerals will be explained in the sequel (p. 503).

It will be observed that many minerals are omitted from this table which, even if they are of common occurrence, are more to be regarded as accessory than as essential components of the rocks in which they are found.[1] Such are, for example, Garnet, Epidote, Tourmaline, Idocrase, Andalusite, Scapolite, the various Zeolites, and several other silicates of somewhat rarer occurrence. Magnetite, Titanoferrite, and Iron-pyrites also occur as normal constituents of various igneous rocks, although in comparatively small amount, as also Apatite, or phosphate of lime. The other salts of lime, including its carbonate or calcite, although often met with, are invariably products of secondary chemical action.

The Zeolites, above mentioned, so named from the manner in which they froth up under the blow-pipe and melt into a glass, differ in their chemical composition from all the other mineral constituents of volcanic rocks since they are hydrated silicates containing from 10 to 25 per cent. of water. They abound in some trappean rocks and ancient lavas, where they fill up vesicular cavities and interstices in the substance of the rocks, but are rarely found in any quantity in recent lavas ; in most cases they are to be regarded as secondary products formed by the action of water on the other constituents of the rocks. Amongst them the species Analcime, Stilbite, Natrolite, and Chabazite may be mentioned as of most common occurrence.

Quartz group.—The microscope has shown that pure quartz is oftener present in lavas than was formerly supposed. It had been argued that the quartz in granite having a specific gravity of 2·6, was not of purely igneous origin, because the silica resulting from fusion in the laboratory has only a specific gravity of 2·3. But Mr. David Forbes has ascertained that the free quartz in trachytes which are known to have flowed as lava, has the same specific gravity as the ordinary quartz of granite, and the recent researches of Vom Rath and others prove that the mineral Tridymite, which is crystallised silica of sp. gr. 2·3 (see Table, p. 498), is of common occurrence in the volcanic rocks of Mexico, Auvergne, the Rhine, and elsewhere, although hitherto entirely overlooked.

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[1] For analyses of these minerals see the Mineralogies of Dana and Bristow.

Felspar group.—In the Felspar group (Table, p. 498) the five mineral species most commonly met with as rock constituents are: 1. Orthoclase, often called common or potash-felspar. 2. Albite or soda-felspar, a mineral which plays a more subordinate part than was formerly supposed, this name having been given to much which has since been proved to be Oligoclase. 3. Oligoclase, or soda-lime-felspar, in which soda is present in much larger proportion than lime, and of which mineral andesite or andesine is considered to be a variety. 4. Labradorite, or lime-soda-felspar, in which the proportions of lime and soda are the reverse to what they are in Oligoclase. 5. Anorthite or lime-felspar. The two latter felspars are rarely found to enter into the composition of rocks containing quartz.

In employing such terms as potash-felspar, &c., it must, however, always be borne in mind that it is only intended to direct attention to the predominant alkali or alkaline earth in the mineral, not to assert the absence of the others, which in most cases will be found to be present in minor quantity. Thus potash-felspar (orthoclase) almost always contains a little soda, and often traces of lime or magnesia; and in like manner with the others. The terms 'glassy' and 'compact' felspars only refer to structure, and not to species or composition; the student should be prepared to meet with any of the above felspars in either of these conditions: the glassy state being apparently due to quick cooling, and the compact to conditions unfavourable to crystallisation; the so-called 'compact felspar' is also very commonly found to be an admixture of more than one felspar species, and frequently also contains quartz and other extraneous mineral matter only to be detected by the microscope. In examining the felspars contained in rocks it is also necessary to bear in mind the changes in lustre and colour, the result of incipient decomposition, to which all the varieties are more or less liable.

Felspars when arranged according to their system of crystallisation are *monoclinic*, having one axis obliquely inclined, or *triclinic*, having the three axes all obliquely inclined to each other. If arranged with reference to their cleavage they are *orthoclastic*, the fracture taking place always at a right angle, or *plagioclastic*, in which the cleavages are oblique to one another. Orthoclase is orthoclastic and monoclinic, all the other felspars are plagioclastic and triclinic. The latter group may often be recognised by the presence of fine parallel striæ, produced by the imperfective junction of the crystals where they blend into each other.

Minerals in meteorites.—That species of the Felspar Group which is called Anorthite has been shown by Rammelsberg to occur in a meteoric stone, and his analysis proves it to be almost identical in its chemical proportions with the same mineral in the lavas of modern volcanos. So also Bronzite (Enstatite) and Olivine have been met with in meteorites and shown by analysis to come remarkably near to these minerals in ordinary rocks.

Mica group.—With regard to the micas, the four principal species (Table, p. 498) all contain potash in nearly the same proportion, but differ greatly in the proportion and nature of their other ingredients. Muscovite is often called common or potash mica; Lepidolite is characterised by containing lithia in addition; Biotite contains a large amount of magnesia and oxide of iron; whilst Phlogopite contains still more of the former substance. In rocks containing quartz, muscovite or lepidolite are most common. The mica in recent volcanic rocks, gabbros, and diorites is usually Biotite, whilst that so common in metamorphic limestones is usually, if not always, Phlogopite.

Amphibole and Pyroxene group.—The minerals included in the table under the Amphibole and Pyroxene Group differ somewhat in their crystalline form, though they all belong to the monoclinic system. Amphibole is a general name for all the different varieties of Hornblende, Actinolite, Tremolite, &c., while Pyroxene may be considered to include Augite, Diallage, Malacolite, Sahlite, Diopside, Hypersthene, Bronzite, &c. The two divisions are so much allied in chemical composition and crystallographic characters, and blend so completely one into the other in Uralite (see p. 498), that it is perhaps best to unite them in one group.

Theory of Isomorphism.—The history of the changes of opinion on this point is curious and instructive. Werner first distinguished augite from hornblende; and his proposal to separate them obtained afterwards the sanction of Haüy, Mohs, and other celebrated mineralogists. It was agreed that the form of the crystals of the two species was different, and also their structure, as shown by *cleavage*, that is to say, by breaking or cleaving the mineral with a chisel, or a blow of the hammer, in the direction in which it yields most readily. It was also found by analysis that augite usually contained more lime, less alumina, and no fluoric acid; which last, though not always found in hornblende, often enters into its composition in minute quantity. In addition to these characters, it was remarked as a geological fact, that augite and hornblende are very rarely associated together in the same rock, augite being present in rocks in which there is but little silica such as Dolerite and Basalt, and hornblende occurring where silica is in excess as in Granite and Syenite. It was also found that in the crystalline slags of furnaces, augitic forms were frequent, the hornblendic entirely absent; hence it was conjectured that hornblende might be the result of slow, and augite of rapid cooling. This view was confirmed by the fact, that Mitscherlich and Berthier were able to make augite artificially, but could never succeed in forming hornblende. Lastly, Gustavus Rose fused a mass of hornblende in a porcelain furnace, and found that it did not, on cooling, assume its previous shape, but invariably took that of augite. The same mineralogist observed certain crystals called Uralite (see Table, p. 498) in rocks from Siberia which possessed the cleavage and chemical composition of hornblende, while they had the external form of augite.

If, from these data, it is inferred that the same substance may assume the crystalline forms of hornblende or augite indifferently, according to the more or less rapid cooling of the melted mass, it is nevertheless certain that the variety commonly called augite, and recognised by a peculiar crystalline form, has usually more lime in it, and less alumina, than that called hornblende, although the quantities of these elements do not seem to be always the same. Unquestionably the facts and experiments above mentioned show the very near affinity of hornblende and augite; but even the convertibility of one into the other, by melting and recrystallising, does not perhaps demonstrate their absolute identity. For there is often some portion of the materials in a crystal which are not in perfect chemical combination with the rest. Carbonate of lime, for example, sometimes carries with it a considerable quantity of silica into its own form of crystal, the silica being mechanically mixed as sand, and yet not preventing the carbonate of lime from assuming the form proper to it. This is an extreme case, but in many others some one or more of the ingredients in a crystal may be excluded from perfect chemical union; and after fusion, when the mass recrystallises, the same elements may combine perfectly or in new proportions, and thus a new mineral may be produced. Or some one of the gaseous elements of the atmosphere, the oxygen for example, may, before the melted matter reconsolidates, have combined with some one or more of the component elements.

The different quantity of the impurities or the refuse above alluded to, which may occur in all but the most transparent and perfect crystals, may partly explain the discordant results at which experienced chemists have arrived in their analysis of the same mineral. For the reader will often find that crystals of a mineral determined to be the same by physical characters, crystalline form, and optical properties, have been declared by skilful analysers to be composed of distinct elements. This disagreement seemed at first subversive of the atomic theory, or the doctrine that there is a fixed and constant relation between the crystalline form and structure of a mineral and its chemical composition. The apparent anomaly, however, which threatened to throw the whole science of mineralogy into confusion, was reconciled to fixed principles by the discoveries of Professor Mitscherlich at Berlin, who ascertained that the composition of the minerals which had appeared so variable was governed by a general law, to which he gave the name of *isomorphism* (from ισος, *isos*, equal, and μορφη, *morphe*, form). According to this law, the ingredients of a given species of mineral are not absolutely fixed as to their kind and quality; but one ingredient may be replaced by an equivalent portion of some analogous ingredient. Thus, in augite, the lime may be in part replaced by portions of protoxide of iron, or of manganese, while the form of the crystal, and the angle of its cleavage planes, remain the same. These vicarious substitutions, however, of particular elements cannot exceed certain defined limits.

Basaltic rocks.—The two principal families of trappean or volcanic rocks are the basalts and the trachytes, which differ chiefly from each other in the quantity of silica which they contain. The basaltic rocks are comparatively poor in silica, containing less than 55 per cent. of that mineral, and none in a pure state or as free quartz, apart from the rest of the matrix. They contain a larger proportion of lime and magnesia than the trachytes, so that they are heavier independently of the frequent presence of the oxides of iron, which in some cases forms more than a fourth part of the whole mass. Abich has therefore proposed that we should ascertain the specific gravity of these rocks, in order to appreciate their composition in cases where it is impossible to separate their component minerals. Thus, basalt from Staffa containing 47·80 per cent. of silica has a specific gravity of 2·95; whereas trachyte, which has 66 per cent. of silica, has a sp. gr. of only 2·68; porphyritic trachyte, containing 69 per cent. of silica, a sp. gr. of only 2·58. If we then take a rock of intermediate composition, such as that prevailing in the Peak of Teneriffe, which Abich calls Trachyte-dolerite, its proportion of silica being intermediate, or 58 per cent., it has a specific gravity of 2·78, or more than trachyte, and less than basalt.[1]

Basalt.—The different varieties of this rock are distinguished by the names of basalts, anamesites, and dolerites, names which, however, only denote differences in texture without implying any difference in mineral or chemical composition: the term *Basalt* being used only when the rock is compact, amorphous, and often semivitreous in texture and when it breaks with a perfect conchoidal fracture; when, however, it is uniformly crystalline in appearance, yet very close-grained, the name *Anamesite* (from ἀνάμεσος, intermediate) is employed, but if the rock be so coarsely crystallised that its different mineral constituents can be easily recognised by the eye, it is called *Dolerite* (from δολερός, deceitful), in allusion to the difficulty of distinguishing it from some of the rocks known as plutonic. The term *Tachylite* is applied to basalt which has assumed the appearance of volcanic glass, and is only distinguishable from obsidian by its greater density and softness.

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[1] Dr. Daubeny on Volcanos, 2nd ed. pp. 14, 15.

Melaphyre is often quite undistinguishable in external appearance from basalt, for although rarely so heavy, dark-coloured or compact, it may present at times all these varieties of texture. Both these rocks are composed of triclinic felspar and augite with more or less olivine, magnetic or titaniferous oxide of iron, and usually a little nepheline, leucite, and apatite; basalt usually contains considerably more olivine than melaphyre, but chemically they are closely allied, although the melaphyres usually contain more silica and alumina with less oxides of iron, lime, and magnesia than the basalts. The term *Melaphyre*, however, although popular with some writers, is very vague in its signification, and therefore of but little scientific value. Many so-called melaphyres have been shown to be true basalts, though sometimes altered by subsequent chemical action.

Greenstone.—This name has usually been extended to all granular mixtures, whether of hornblende and felspar, or of augite and felspar. *Labrador-rock* is a term used for a compound of labradorite or labrador-felspar and hypersthene; when the hypersthene predominates it is sometimes known under the name of *Hypersthene-rock*, *Hypersthenite* or *Hyperite*. *Diorite*, *Gabbro* and *Diabase* are very crystalline rocks which help to connect the volcanic with the plutonic formations; they will therefore be treated of in Chapter XXXI.

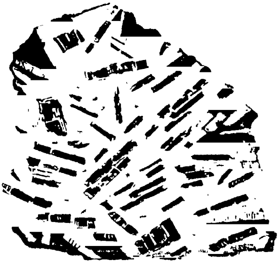
Trachytic rocks.—The name trachyte (from τραχύς, rough) was originally given to a coarse granular felspathic rock which was rough and gritty to the touch. The term was subsequently made to include other rocks, such as clinkstone and obsidian, which have the same mineral composition, but to which, owing to their different texture, the word in its original meaning would not apply. The felspars which occur in Trachytic rocks are invariably those which contain the largest proportion of silica or from 60 to 70 per cent. of that mineral. Through the base are usually disseminated crystals of glassy felspar, mica, and sometimes hornblende. Although quartz is not a necessary ingredient in the composition of this rock, it is very frequently present, and the quartz trachytes are very largely developed in many volcanic districts. In this respect the trachytes differ entirely from the members of the Basaltic family and in chemical composition are more nearly allied to the granites.

Obsidian.—Obsidian, Pitchstone, and Pearlstone are only different forms of a volcanic glass produced by the fusion of trachytic rocks. The distinction between them is caused by different rates of cooling from the melted state, as has been proved by experiment. Obsidian is of a black, dark-green, or ash-grey colour, and though opaque in mass is translucent at the edges. Pitchstone has a more resinous lustre, and is often lighter in colour than obsidian.

Clinkstone or Phonolite.—Among the rocks closely allied to the trachytes, or those in which the felspars are rich in silica, that termed Clinkstone or Phonolite is conspicuous by its fissile structure, and its tendency to lamination, which is such as sometimes to render it useful as roofing-slate. It rings when struck with the hammer, whence its name ; is compact, and usually of a greyish blue or brownish colour, and is composed of that variety of orthoclase felspar called sanidine, together with nepheline and frequently a little hornblende. The name Clinkstone has often been loosely applied to a mere variety of felstone. The only true Phonolite yet recognised in England is that of the Wolf Rock, off the coast of Cornwall.

Volcanic rocks distinguished by special forms of structure.—Many volcanic rocks are commonly spoken of under names, denoting structure alone, which must not be taken to imply that they are distinct rocks, *i.e.* that they differ from one another either in mineral or chemical composition. Thus the terms Trachytic porphyry, Trachytic tuff, &c., merely refer to the same rock under different conditions of mechanical aggregation or crystalline development which would be more correctly expressed by the use of the adjective, as porphyritic trachyte, &c. ; but as these terms are so commonly employed it is considered advisable to direct the student's attention to them.

Fig. 596.

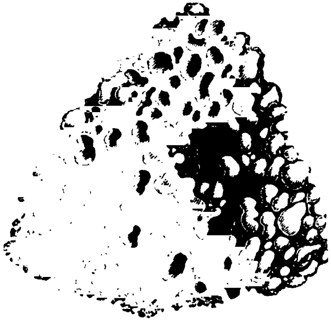


Porphyry.
White crystals of felspar in a dark base of hornblende and felspar.

Porphyry is one of this class, and very characteristic of the volcanic formations. When distinct crystals of one or more minerals are scattered through a compact base, the rock is termed a porphyry (see fig. 596). Thus trachyte is usually porphyritic ; for in it, as in many modern lavas, there are crystals of felspar; but in some porphyries the crystals are of augite, olivine, or other minerals. If the base be greenstone, basalt, or pitchstone, the rock is often denominated greenstone-porphyry, pitchstone-porphyry, and so forth. The old classical type of this form of rock is the red porphyry of Egypt, or the well-known 'Rosso antico.' It consists, according to Delesse, of a red felspathic base in which are disseminated rose-coloured crystals of the felspar called oligoclase, with some plates of blackish hornblende and grains of oxide of iron (iron-glance). *Red quartziferous porphyry* is a much more siliceous rock, containing about 70 or 80 per cent. of silex, while that of Egypt has only 62 per cent.

Amygdaloid.—This is also another form of igneous rock, admitting of great variety of composition, and not peculiar to any geological period. It comprehends any rock in which round or almond-shaped nodules of some mineral, such as agate, calcedony, calcareous spar, or zeolite, are scattered through a base of basalt, or other kind of trap. It derives its name from the Greek word *amygdalon*, an almond. The origin of this structure cannot be doubted, for we may trace the process of its formation in modern lavas. Small pores or cells are caused by bubbles of steam and gas confined in the melted matter. After or during consolidation, these empty spaces are gradually filled up by matter separating from the mass, or infiltered by water permeating the rock. As these bubbles have been sometimes lengthened by the flow of the lava before it finally cooled, the contents of such cavities have the form of almonds. In some of the amygdaloidal traps of Scotland, where the nodules have decomposed, the empty cells are seen to have a glazed or vitreous coating, and in this respect exactly resemble scoriaceous lavas, or the slags of furnaces.

Fig. 597.



Scoriaceous lava in part converted into an amygdaloid.
Montagne de la Veille, Department of Puy de Dome, France.

The annexed figure represents a fragment of stone taken from the upper part of a sheet of basaltic lava in Auvergne. One half is scoriaceous, the pores being perfectly empty ; the other part is amygdaloidal, the pores or cells being mostly filled up with carbonate of lime, forming white kernels.

Lava.—This term has a somewhat vague signification, having been applied to all melted matter observed to flow in streams from volcanic vents. When this matter consolidates in the open air, the upper part is usually scoriaceous, and the mass becomes more and more stony as we descend, or in proportion as it has consolidated more slowly and under greater pressure. At the bottom, however, of a stream of lava, a small portion of scoriaceous rock very frequently occurs, formed by the first thin sheet of liquid matter, which often precedes the main current, and solidifies under slight pressure.

The more compact lavas are often porphyritic, but even the scoriaceous part sometimes contains imperfect crystals, which have been derived from some older rocks, in which the crystals pre-existed, but were not melted, as being more infusible in their nature. Although melted matter rising in a crater, and even that which enters a rent on the side of a crater, is called lava, yet this term belongs more properly to that which has flowed either in the open air or on the bed of a lake or sea. There is every variety of composition in lavas ; some are trachytic, as in the Peak of Teneriffe ; a great number are basaltic, as in Auvergne ; others are andesitic, as those of Chili ; and many of those of Etna consist of dolerites with labrador-felspar.[1]

Scoriæ and *Pumice* may next be mentioned as porous rocks, produced by the action of gases on materials melted by volcanic heat. *Scoriæ* are usually of a reddish-brown and black colour, and are the cinders and slags of basaltic or augitic lavas. *Pumice* is a light, spongy fibrous substance, produced by the action of gases on trachytic and other lavas ; the relation, however, of its origin to the composition of lava is not yet well understood. Von Buch says that it never occurs where only labrador-felspar is present.

Volcanic ash or tuff, Trap tuff.—Small angular fragments of the scoriæ and pumice, above-mentioned, and the dust of the same, produced by volcanic explosions, form the tuffs which abound in all regions of active volcanos, where showers of these materials, together with small pieces of other rocks ejected from the crater, and more or less burnt, fall down upon the land or into the sea. Here they often become mingled with shells, and are stratified. Such tuffs are sometimes bound together by a calcareous cement, and form a stone susceptible of a beautiful polish. But even when little or no lime is present, there is a great tendency in the materials of ordinary tuffs to cohere together. The term *Volcanic ash* has been much used for rocks of all ages supposed to have been derived from matter ejected in a melted state from volcanic orifices. We meet occasionally with extremely compact beds of volcanic materials, interstratified with fossiliferous rocks. These may sometimes be tuffs, although their density or compactness is such as to cause them to resemble many of those kinds of trap which are found in ordinary dikes.

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[1] G. Hose, Ann. des Mines, tom. viii. p. 32.

Wacke is a name given to a decomposed state of various trap rocks of the basaltic family, or those which are poor in silica. It resembles clay of a yellowish or brown colour, and passes gradually from the soft state to the hard dolerite, greenstone or other trap rock from which it has been derived.

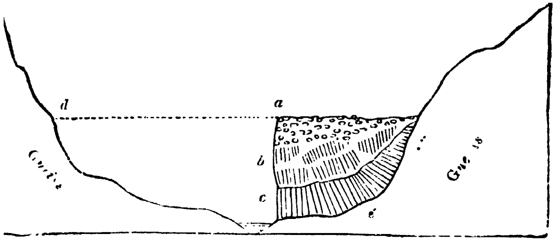
Agglomerate.—In the neighbourhood of volcanic vents, we frequently observe accumulations of angular fragments of rocks formed during eruptions by the explosive action of steam, which shatters the subjacent stony formations and hurls them up into the air. They then fall in showers around the cone or crater, or may be spread for some distance over the surrounding country. The fragments consist usually of different varieties of scoriaceous and compact lavas; but other kinds of rock, such as granite or even fossiliferous limestones, may be intermixed; in short, any substance through which the expansive gases have forced their way. The dispersion of such materials may be aided by the wind, as it varies in direction or intensity, and by the slope of the cone down which they roll, or by floods of rain, which often accompany eruptions. But if the power of running water, or of the waves and currents of the sea, be sufficient to carry the fragments to a distance, it can scarcely fail to wear off their angles, and the formation then becomes a *conglomerate.* If occasionally globular pieces of scoriæ abound in an agglomerate, they may not owe their round form to attrition. When all the angular fragments are of volcanic rocks the mass is usually termed a *volcanic breccia.*

Laterite is a red or brick-like rock composed of silicate of alumina and oxide of iron. The red layers, called 'ochre beds,' dividing the lavas of the Giant's Causeway, which are often called Bole or Lithomarge, appear to be analogous to the Indian laterites. These were found by Delesse to be trap impregnated with the red oxide of iron, and in part reduced to kaolin. When still more decomposed they were found to be clay coloured by red ochre. As two of the lavas of the Giant's Causeway are parted by a bed of lignite, it is not improbable that the red layers seen in the Antrim cliffs resulted from atmospheric decomposition. In Madeira and the Canary Islands streams of lava of subaërial origin are often divided by red bands of laterite, probably ancient soils formed by the decomposition of the surfaces of lava-currents, many of these soils having been coloured red in the atmosphere by oxide of iron, others burnt into a red brick by the overflowing of heated lavas. These red bands are sometimes prismatic, the small prisms being at right angles to the sheets of lava. Red clay or red marl, formed as above stated by the disintegration of lava, scoriæ, or tuff, has often accumulated to a great thickness in the valleys of Madeira, being washed into them by alluvial action; and some of the thick beds of laterite in India may have had a similar origin. In India, however, especially in the Deccan, the term 'laterite' seems to have been used too vaguely to answer the above definition. The vegetable soil in the gardens of the suburbs of Catania which was overflowed by the lava of 1669 was turned or burnt into a layer of red brick-coloured stone, similar to laterite, which may now be seen supporting the old lava-current.

Columnar and globular structure.—One of the characteristic forms assumed by volcanic rocks is the columnar, a structure often displayed in a very striking manner by basaltic lavas. The columns are sometimes straight, at others curiously curved and twisted; in section they are polygonal, and they are often divided longitudinally by equidistant joints, which sometimes exhibit curved surfaces of articulation; in certain cases the angles of one division of a column are found to project and to form processes which fit into sockets, corresponding to them in the adjoining divisions. Columns of different varieties often occur in the same lava stream, the thick straight articulated columns being found in the lower, and the smaller curved forms in its upper portion; and the line of junction between the two varieties is in many cases very distinctly marked. It is this peculiar combination of columns of different kinds which gives rise to the beautiful and well-known features of the Isle of Staffa; it is equally well seen in many lavas of recent date.

It being assumed that columnar trap has consolidated from a fluid state, the prisms are said to be always at right angles to the *cooling surfaces*. If these surfaces, therefore, instead of being either perpendicular or horizontal, are curved, the columns ought to be inclined at every angle to the horizon; and there is a beautiful exemplification of this phenomenon in one of the valleys of the Vivarais, a mountainous district in the South of France, where, in the midst of a region of gneiss, a geologist encounters unexpectedly several volcanic cones of loose sand and scoriæ. From the crater of one of these cones, called La Coupe d'Ayzac, a stream of lava has descended and occupied the bottom of a narrow valley, except at those points where the river Volant, or the torrents which join it, have cut away portions of the solid lava. The accompanying sketch (fig. 598) represents the remnant of the lava at one of these points. It is clear that the lava once filled the whole valley up to the dotted line *d a*; but the river has gradually swept away all below that line, while the tributary torrent has laid open a transverse section; by which we perceive, in the first place, that the lava is composed, as usual in this country, of three parts: the uppermost, at *a*, being scoriaceous; the second, *b*, presenting irregular prisms; and the third, *c*, with regular columns, which are vertical on the banks of the Volant, where they rest on a horizontal base of gneiss, but which are inclined at an angle of 45° at *g*, and are nearly horizontal at *f*, their position having been everywhere determined, according to the law before mentioned, by the form of the original valley.

Fig. 598.



Lava of La Coupe d'Ayzac, near Antraigue, in the Department of Ardêche.

In the annexed figure 599, a view is given of some of the inclined and curved columns which present themselves on the sides of the valleys in the hilly region north of Vicenza in Italy and at the foot of the higher Alps.[1] Unlike those of the Vivarais, last mentioned, the basalt of this country was evidently submarine, and the present valleys have since been hollowed out by denudation.

The columnar structure is by no means peculiar to the trap

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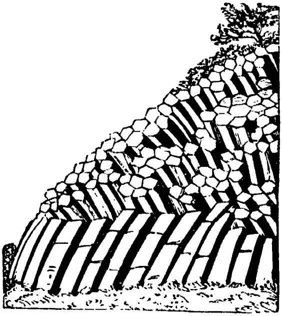
[1] Fortis, Mém. sur l'Hist. Nat. de l'Italie, tom. i. p. 233, plate 7.

rocks in which augite abounds; it is also observed in trachyte, and other felspathic rocks of the igneous class, although in these it is rarely exhibited in such regular polygonal forms, with ball and socket joints, which form so conspicuous a feature in many basaltic columns. It has been already stated that basaltic columns are often divided by cross joints. Sometimes each segment, instead of an angular, assumes a spheroidal form, usually produced by weathering, so that a pillar is made up of a pile of balls, usually flattened, as in the Cheese-grotto at Bertrich-Baden, in the Eifel, near the Moselle (fig. 600). The basalt there is part of a small stream of lava, from 30 to 40 feet thick, which has proceeded from one of several volcanic craters, still extant, on the neighbouring heights.

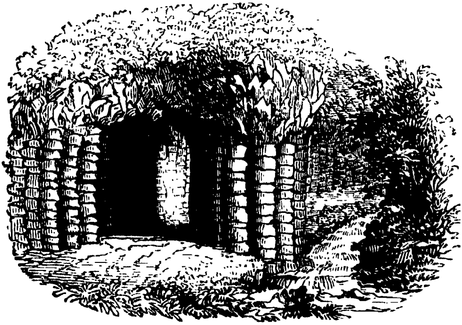
Fig. 599.



Columnar basalt in the Vicentin. (Fortis.)

In some masses of decomposing basalt, greenstone, and other trap rocks, the globular structure is so conspicuous that the rock has the appearance of a heap of large cannon balls. According to M. Delesse, the centre of each spheroid has been a centre of crystallisation, around which the different minerals of the rock arranged themselves symmetrically during the process of cooling. But it was also, he says, a centre of contraction, pro-

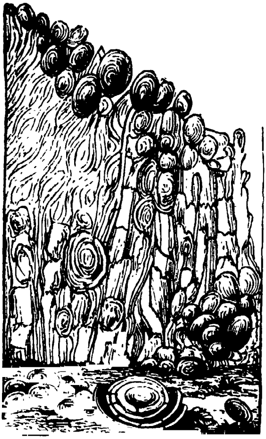
Fig. 600.



Basaltic pillars of the Käsegrotte, Bertrich-Baden, half way between Trèves and Coblentz. Height of grotto, from 7 to 8 feet.

duced by the same cooling, the globular form, therefore, of such spheroids being the combined result of crystallisation and contraction.[1] To this same contraction we may attribute some cases of columnar structure in sedimentary strata such as volcanic ash, shale and sandstone, which had been heated by the proximity of volcanic dikes.

Fig. 601.



Globiform pitchstone. Chiaja di Luna, Isle of Ponza. (Scrope.)

Mr. Scrope gives as an illustration of this structure a resinous trachyte or pitchstone-porphyry in one of the Ponza islands, which rise from the Mediterranean, off the coast of Terracina and Gaeta. The globes vary from a few inches to three feet in diameter, and are of an ellipsoidal form (see fig. 601). The whole rock is in a state of decomposition, 'and when the balls,' says Mr. Scrope, 'have been exposed a short time to the weather, they scale off at a touch into numerous concentric coats, like those of a bulbous root, inclosing a compact nucleus. The laminæ of this nucleus have not been so much loosened by decomposition; but the application of a ruder blow will produce a still further exfoliation.'[2] This spheroidal structure may be also seen in volcanic ash at Burntisland and elsewhere.

Volcanic or Trap Dikes.—The leading varieties of the trappean rocks—basalt, trachyte, and the rest—are found sometimes in dikes penetrating stratified and unstratified formations, sometimes in shapeless masses protruding through or overlying them, or in horizontal sheets intercalated between strata. Fissures have already been spoken of as occurring in all kinds of rocks, some a few feet, others many yards in width, and often filled up with earth or angular pieces of stone, or with sand and pebbles. Instead of such materials, suppose a quantity of melted stone to be driven or injected into an open rent, and there consolidated, we have then a tabular mass resembling a wall, and called a trap dike. It is not uncommon to find such dikes passing through strata of soft materials, such as tuff, scoriæ, or shale, which, being more perishable than the trap, are often washed away by the sea, rivers, or rain, in which case the dike stands prominently out on the face of precipices, or on the level surface of a country, as may be seen in Madeira (see fig. 602) and in many parts of Scotland.

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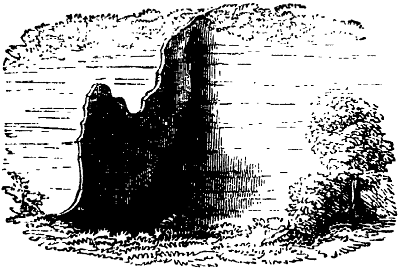
[1] Delesse, Sur les Roches Globuleuses, Mém. de la Soc. Géol. de France, 2 sér. tom. iv.

[2] Scrope, Geol. Trans. 2nd series, vol. ii. p. 205.

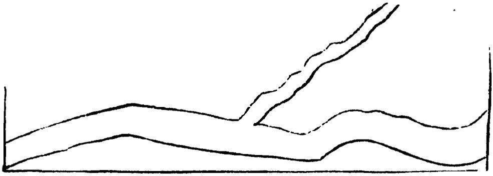
Fig. 602.



Dike in valley, near Brazen Head, Madeira. (From a drawing of Capt. Basil Hall, R.N.)

In the islands of Arran and Skye, and in other parts of Scotland, where sandstone, conglomerate, and other hard rocks are traversed by dikes of trap, the converse of the above phenomenon is also seen. The dike, having decomposed more rapidly than the containing rock, has once more left open the original fissure, often for a distance of many yards inland from the seacoast. There is yet another case, by no means uncommon in Arran and other parts of Scotland, where the strata in contact with the dike, and for a certain distance from it, have been hardened, so as to resist the action of the weather more than the dike itself or the surrounding rocks. When this happens, two parallel walls of indurated strata are seen protruding above the general level of the country and following the course of the dike. In fig. 603, a ground plan is given of a ramifying dike of greenstone, which I observed cutting through sandstone on

Fig. 603.



Ground plan of greenstone dikes traversing sandstone. Arran.

the beach near Kildonan Castle, in Arran. The larger branch varies from 5 to 7 feet in width, which will afford a scale of measurement for the whole.

In the Hebrides and other countries, the same masses of trap which occupy the surface of the country far and wide, concealing the subjacent stratified rocks, are seen also in the sea cliffs, prolonged downwards in veins or dikes, which probably unite with other masses of igneous rock at a greater depth.

Every variety of trap-rock is sometimes found in dikes, as trachyte, basalt, and all the greenstones, besides the different felstones. The amygdaloidal traps also occur, though more rarely, and even tuff and breccia, for the materials of these last may be washed down into open fissures at the bottom of the sea, or during eruption on the land may be showered into them from the air. Some dikes of trap may be followed for leagues uninterruptedly in nearly a straight direction, as in the North of England, showing that the fissures which they fill must have been of extraordinary length.

Rocks altered by volcanic dikes.—After these remarks on the form and composition of dikes themselves, I shall describe the alterations which they sometimes produce in the rocks in contact with them. The changes are usually such as the heat of melted matter and of the entangled steam and gases might be expected to cause.

Plas-Newydd: Dike cutting through shale.—A striking example, near Plas-Newydd, in Anglesea, has been described by Professor Henslow.[1] The dike is 134 feet wide, and consists of a rock which is a compound of triclinic felspar and augite. Strata of shale and argillaceous limestone, through which it cuts perpendicularly, are altered to a distance of 30, or even in some places, of 35 feet from the edge of the dike. The shale, as it approaches the trap, becomes gradually more compact, and is most indurated where nearest the junction. Here it loses part of its schistose structure, but the separation into parallel layers is still discernible. In several places the shale is converted into hard porcellanous jasper. In the most hardened part of the mass the fossil shells, principally *Producti*, are nearly obliterated; yet even here their impressions may frequently be traced. The argillaceous limestone undergoes analogous mutations, losing its early texture as it approaches the dike, and becoming granular and crystalline. But the most extraordinary phenomenon is the appearance in the shale of numerous crystals of analcime and garnet, which are distinctly confined to those portions of the rock affected by the dike.[2]

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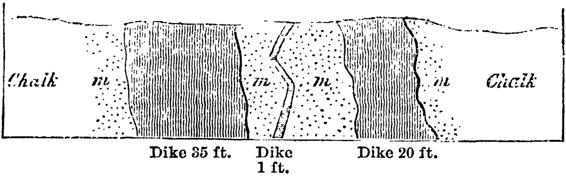
[1] Cambridge Transactions, vol. i. p. 402.

[2] Ibid., vol. i. p. 410.

Some garnets contain as much as 20 per cent. of lime, which they may have derived from the decomposition of the fossil shells or *Producti.* The same mineral has been observed, under very analogous circumstances, in High Teesdale, by Professor Sedgwick, where it also occurs in shale and limestone, altered by basalt.[1]

Antrim: Dike cutting through chalk.—In several parts of the county of Antrim, in the north of Ireland, chalk with flints is traversed by basaltic dikes. The chalk is there converted into granular marble near the basalt, the change sometimes extending 8 or 10 feet from the wall of the dike, being greatest near the point of contact, and thence gradually decreasing till it becomes evanescent. 'The extreme effect,' says Dr. Berger, 'presents a dark brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive (*metamorphic*) limestone; the next state is saccharine, then fine grained and arenaceous; a compact variety, having a porcellanous aspect and a bluish-grey colour, succeeds: this, towards the outer edge, becomes yellowish-white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour.'[2] All traces of organic remains are effaced in that part of the limestone which is most crystalline.

Fig. 604.



Basaltic dikes in chalk in Island of Rathlin, Antrim.
Ground plan as seen on the beach. (Conybeare and Buckland.[3])

The annexed drawing (fig. 604) represents three basaltic dikes traversing the chalk, all within the distance of 90 feet. The chalk contiguous to the two outer dikes is converted into a finely granular marble, *m m*, as are the whole of the masses between the outer dikes and the central one. In some cases the change undergone by the chalk is of a chemical nature, and the rock, besides being indurated and crystallised, is also dolomitised. The entire contrast in the composition and colour

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[1] Cambridge Transactions, vol. ii. p. 175.

[2] Dr. Berger, Geol. Trans. 1st ser. vol. iii. p. 172.

[3] Geol. Trans. 1st series, vol. iii. p. 210, and plate 10.

It is by no means uncommon to meet with the same rocks, even in the same districts, almost wholly unchanged in the proximity of volcanic dikes. This great inequality in the effects of the igneous rocks may often arise from an original difference in their temperature, and in that of the entangled gases, such as is ascertained to prevail in different lavas, or in the same lava near its source and at a distance from it. The power also of the invaded rocks to conduct heat may vary, according to their composition, structure, and the fractures which they may have experienced, and perhaps, also, according to the quantity of water (so capable of being heated) which they contain. It must happen in some cases that the component materials are mixed in such proportions as to prepare them readily to enter into chemical union, and form new minerals; while in other cases the mass may be more homogeneous, or the proportions less adapted for such union.

We must also take into consideration, that one fissure may be simply filled with lava, which may begin to cool from the first; whereas in other cases the fissure may give passage to a current of melted matter, which may ascend for days or months, feeding streams which are overflowing the country above, or being ejected in the shape of scoriæ from some crater. If the walls of a rent, moreover, are heated by hot vapour before the

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[1] Geol. Trans. 1st series, vol. iii. p. 213; and Playfair, Illust. of Hutt. Theory, s. 253.

[2] Sedgwick, Camb. Trans., vol. ii. p. 37.

lava rises, as we know may happen on the flanks of a volcano, the additional heat supplied by the dike and its gases will act more powerfully.

Intrusion of trap between strata.—Masses of trap are not unfrequently met with intercalated between strata, and maintaining their parallelism to the planes of stratification throughout large areas. They must in some places have forced their way laterally between the divisions of the strata, a direction in which there would be the least resistance to an advancing fluid, if no vertical rents communicated with the surface, and a powerful hydrostatic pressure were caused by gases propelling the lava upwards.

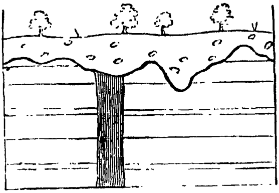
Relation of Trappean rocks to the products of active volcanos.—When we reflect on the changes above described in strata near their contact with trap dikes, and consider how complete is the analogy or often identity in composition and structure of the rocks called trappean and the lavas of active volcanos, it seems difficult at first to understand how so much doubt could have prevailed for half a century as to whether trap was of igneous or aqueous origin. To a certain extent, however, there was a real distinction between the trappean formations and those to which the term volcanic was almost exclusively confined. A large portion of the trappean rocks first studied in the north of Germany, and in Norway, France, Scotland, and other countries, were such as had been formed entirely under water, or had been injected into fissures and intruded between strata, and which had never flowed out in the air, or over the bottom of a shallow sea. When these products, therefore, of submarine or subterranean igneous action were contrasted with loose cones of scoriæ, tuff, and lava, or with narrow streams of lava in great part scoriaceous and porous, such as were observed to have proceeded from Vesuvius and Etna, the resemblance seemed remote and equivocal. It was, in truth, like comparing the roots of a tree with its leaves and branches, which, although they belong to the same plant, differ in form, texture, colour, mode of growth, and position. The external cone, with its loose ashes and porous lava, may be likened to the light foliage and branches, and the rocks concealed far below, to the roots. But it is not enough to say of the volcano,

quantum vertice in auras
Ætherias, tantum radice in Tartara tendit,

for its roots do literally reach downwards to Tartarus, or to the regions of subterranean fire; and what is concealed far below is probably always more important in volume and extent than what is visible above ground.

We have already stated how frequently dense masses of strata have been removed by denudation from wide areas (see Chap. VI.); and this fact prepares us to expect a similar destruction of whatever may once have formed the uppermost part of ancient submarine or subaërial volcanos, more especially a those superficial parts are always of the lightest and most perishable materials. The abrupt manner in which dikes of trap usually terminate at the surface (see fig. 605), and the water-worn pebbles of trap in the alluvium which covers the dike, prove incontestably that whatever was uppermost in these formations has been swept away. It is easy, therefore, to conceive that what is gone in regions of trap may have corresponded to what is now visible in active volcanos.

Fig. 605.



Strata intercepted by a trap dike, and covered with alluvium.

As to the absence of porosity in the trappean formations, the appearances are in a great degree deceptive, for all amygdaloids are, as already explained, porous rocks, into the cells of which mineral matter such as silex, carbonate of lime, and other ingredients, have been subsequently introduced (see p. 506); sometimes, perhaps, by secretion during the cooling and consolidation of lavas. In the Little Cumbray, one of the Western Islands, near Arran, the amygdaloid sometimes contains elongated cavities filled with brown spar; and when the nodules have been washed out, the interior of the cavities is glazed with the vitreous varnish so characteristic of the pores of slaggy lavas. Even in some parts of this rock which are excluded from air and water, the cells are empty, and seem to have always remained in this state, and are therefore undistinguishable from some modern lavas.[1]

Dr. MacCulloch, after examining with great attention these and the other igneous rocks of Scotland, observes, 'that it is a mere dispute about terms, to refuse to the ancient eruptions of trap the name of submarine volcanos; for they are such in every essential point, although they no longer eject fire and smoke.' The same author also considers it not improbable that some of the volcanic rocks of the same country may have been poured out in the open air.[1]

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[1] MacCulloch, West. Islands, vol. ii. p. 487.

It will be seen in the following chapters, that in the earth's crust there are volcanic tuffs of all ages, containing marine shells, which bear witness to eruptions at many successive geological periods. These tuffs, and the associated trappean rocks, must not be compared to lava and scoriæ which have cooled in the open air. Their counterparts must be sought in the products of modern submarine volcanic eruptions. If it be objected that we have no opportunity of studying these last, it may be answered, that subterranean movements have caused, almost everywhere in regions of active volcanos, great changes in the relative level of land and sea, in times comparatively modern, so as to expose to view the effects of volcanic operations at the bottom of the sea.

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[1] Syst. of Geol., vol. ii. p. 114.

CHAPTER XXIX.

ON THE AGES OF VOLCANIC ROCKS.

Tests of relative age of volcanic rocks—Why ancient and modern rocks cannot be identical—Tests by superposition and intrusion—Test by alteration of rocks in contact—Test by organic remains—Test of age by mineral character—Test by included fragments—Post-Tertiary volcanic rocks—Vesuvius, Auvergne, Puy de Côme, and Puy de Pariou—Newer Pliocene volcanic rocks—Cyclopean Isles, Etna, Dikes of Patagonia, Madeira—Older Pliocene volcanic rocks—Italy—Pliocene volcanos of the Eifel—Trass.

Having in the former part of this work referred the sedimentary strata to a long succession of geological periods, we have now to consider how far the volcanic formations can be classed in a similar chronological order. The tests of relative age in this class of rocks are four: 1st, superposition and intrusion, with or without alteration of the rocks in contact; 2nd, organic remains; 3rd, mineral characters; 4th, included fragments of older rocks.

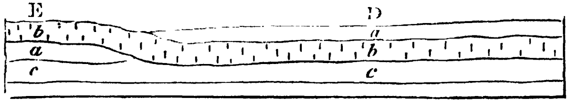
Besides these four tests it may be said in a general way, that volcanic rocks of Primary or Palæozoic antiquity differ from those of the Secondary or Mesozoic age, and these again from the Tertiary and Recent. Not perhaps that they differed originally in a greater degree than the modern volcanic rocks of one region, such as that of the Andes, differ from those of another such as Iceland, but because all rocks permeated by water, especially if its temperature be high, are liable to undergo a slow transmutation, even when they do not assume a new crystalline form like that of the hypogene rocks.

Although subaërial and submarine denudation, as before stated, remove, in the course of ages, large portions of the upper or more superficial products of volcanos, yet these are sometimes preserved by subsidence, becoming covered by the sea or by superimposed marine deposits. In this way they may be protected for ages from the waves of the sea, or the destroying action of rivers, while, at the same time, they may not sink so deep as to be exposed to that plutonic action (to be spoken of in Chapter XXXI.), which would convert them into crystalline rocks. But even in this case, they will not remain unaltered, because they will be percolated by water often of high temperature and charged with carbonate of lime, silex, iron, and other mineral ingredients, whereby gradual changes in the constitution of the rocks may be superinduced. Every geologist is aware how often silicified trees occur in volcanic tuffs, the perfect preservation of their internal structure showing that they have not decayed before the petrifying material was supplied.

The porous and vesicular nature of a large part, both of the basaltic and trachytic lavas, affords cavities in which silex and carbonate of lime are readily deposited. The minerals of the zeolite family which are so commonly found in amygdaloidal cavities are closely related in composition to the felspars, which, however, differ in being anhydrous. Daubrée and others have shown that the zeolites are formed by the action of percolating water upon the felspathic ingredients of rocks, while Bunsen has also shown in his researches into the volcanic rocks of Iceland that they may be formed directly in molten masses. From these considerations it follows that the perfect identity of very ancient and very modern volcanic formations is scarcely possible.

Tests by superposition.—If a volcanic rock rest upon an aqueous deposit, the volcanic must be the newest of the two; but the like rule does not hold good where the aqueous formation rests upon the volcanic, for melted matter, rising from below, may penetrate a sedimentary mass without reaching the surface, or may be forced in conformably between two strata, as *b* below D in the annexed figure (fig. 606), after which it may cool down and consolidate. Superposition, therefore, is not of the same value as a test of age in the unstratified volcanic rocks as in fossiliferous formations. We can only rely implicitly on this test where the volcanic rocks are contemporaneous, not where they are intrusive. Now, they are said to be contemporaneous if produced by volcanic action which was going on simultaneously with the deposition of the strata with which they are associated. Thus in the section at D (fig. 606), we may perhaps ascertain that the trap *b* flowed over the fossiliferous bed *c*, and that, after its consolidation, *a* was deposited upon it, *a* and *c* both belonging to the same geological period. But, on the other hand, we must conclude the trap to be intru-

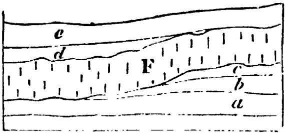
Fig. 606.



sive, if the stratum *a* be altered by *b* at the point of contact, or if, in pursuing *b* for some distance, we find at length that it cuts through the stratum *a*, and then overlies it as at E.

We may, however, be easily deceived in supposing the volcanic rock to be intrusive, when in reality it is contemporaneous; for a sheet of lava, as it spreads over the bottom of the sea, cannot rest everywhere upon the same stratum, either because these have been denuded, or because, if newly thrown down, they thin out in certain places, thus allowing the lava to cross their edges. Besides the heavy igneous fluid will often, as it moves along, cut a channel into beds of soft mud and sand. Suppose the submarine lava F (fig. 607) to have come in contact in this manner with the strata *a*, *b*, *c*, and that after its consolidation the strata *d*, *e*, are thrown down in a nearly horizontal position, yet so as to lie unconformably to F, the appearance of subsequent intrusion will here be complete, although the trap is in fact contemporaneous. We must not, therefore, hastily infer that the rock F is intrusive, unless we find the overlying strata *d*, *e*, to have been altered at their junction, as if by heat.

Fig. 607.



The test of age by superposition is strictly applicable to all stratified volcanic tuffs, according to the rules already explained in the case of sedimentary deposits (see p. 101).

Test of age by organic remains.—We have seen how, in the vicinity of active volcanos, scoriæ, pumice, fine sand, and fragments of rock are thrown up into the air, and then showered down upon the land, or into neighbouring lakes or seas. In the tuffs so formed shells, corals, or any other durable organic bodies which may happen to be strewed over the bottom of a lake or sea will be embedded, and thus continue as permanent memorials of the geological period when the volcanic eruption occurred. Tufaceous strata thus formed in the neighbourhood of Vesuvius, Etna, Stromboli, and other volcanos now in islands or near the sea, may give information of the relative age of these tuffs at some remote future period when the fires of these mountains are extinguished. By evidence of this kind we can establish a coincidence in age between volcanic rocks and the different primary, secondary, and tertiary fossiliferous strata.

The tuffs alluded to may not always be marine, but may include, in some places, freshwater shells; in others, the bones of terrestrial quadrupeds. The diversity of organic remains in formations of this nature is perfectly intelligible, if we reflect on the wide dispersion of ejected matter during late eruptions, such as that of the volcano of Coseguina, in the province of Nicaragua, January 19, 1835. Hot cinders and fine scoriæ were then cast up to a vast height, and covered the ground as they fell to the depth of more than 10 feet for a distance of 8 leagues from the crater in a southerly direction. Birds, cattle, and wild animals were scorched to death in great numbers, and buried in ashes. Some volcanic dust fell at Chiapa, upwards of 1,200 miles, not to leeward of the volcano as might have been anticipated, but to windward, a striking proof of a counter-current in the upper region of the atmosphere; and some on Jamaica, about 700 miles distant to the north-east. In the sea, also, at the distance of 1,100 miles from the point of eruption, Captain Eden of the 'Conway' sailed 40 miles through floating pumice, among which were some pieces of considerable size.[1]

Test of age by mineral composition.—As sediment homogeneous composition, when discharged from the mouth of a large river, is often deposited simultaneously over a wide space, so a particular kind of lava flowing from a crater during one eruption, may spread over an extensive area; thus in Iceland in 1783, the melted matter, pouring from Skaptar Jokul, flowed in streams in opposite directions, and caused a continuous mass the extreme points of which were 90 miles distant from each other. This enormous current of lava varied in thickness from 100 feet to 600 feet, and in breadth from that of a narrow river gorge to 15 miles.[2] Now, if such a mass should afterwards be divided into separate fragments by denudation, we might still perhaps identify the detached portions by their similarity in mineral composition. Nevertheless, this test will not always avail the geologist; for, although there is usually a prevailing character in lava emitted during the same eruption, and even in the successive currents flowing from the same volcano, still, in many cases, the different parts even of one lava-stream, or, as before stated, of one continuous mass of trap, vary much in mineral composition and texture.

In Auvergne, the Eifel, and other countries where trachyte and basalt are both present, the trachytic rocks are for the most part older than the basaltic. These rocks do, indeed, sometimes alternate partially, as in the volcano of Mount Dore, in Auvergne: and in Madeira trachytic rocks overlie an older basaltic series ; but the trachyte occupies more generally an inferior position, and is cut through and overflowed by basalt. It can by no means be inferred that trachyte predominated at one period of the earth's history and basalt at another, for we know that trachytic lavas have been formed at many successive periods, and are still emitted from many active craters ; but it seems that in each region, where a long series of eruptions have occurred, the lavas containing felspar more rich in silica have been first emitted, and the escape of the more augitic kinds has followed. The hypothesis suggested by Mr. Scrope may, perhaps, afford a solution of this problem. The minerals, he observes, which abound in basalt are of greater specific gravity than those composing the felspathic lavas ; thus, for example, both augite and olivine are more than three times as heavy as water ; whereas orthoclase and quartz have a specific gravity of little more than 2·5 ; and the difference is increased in consequence of there being usually much more iron in state of oxide in basaltic than in trachytic lavas. If, therefore, a large quantity of rock be melted up in the bowels of the earth by volcanic heat, the denser ingredients of the boiling fluid may sink to the bottom, and the lighter remaining above would in that case be first propelled upwards to the surface by the expansive power of gases. Those materials, therefore, which occupy the lowest place in the subterranean reservoir will always be emitted last, and take the uppermost place on the exterior of the earth's crust.

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[1] Caldcleugh, Phil. Trans. 1836, p. 27.

[2] See Principles, *Index*, 'Skaptar Jokul.'

Test by included fragments.—We may sometimes discover the relative age of two trap rocks, or of an aqueous deposit and the trap on which it rests, by finding fragments of one included in the other in cases such as those before alluded to, where the evidence of superposition alone would be insufficient. It is also not uncommon to find a conglomerate almost exclusively composed of rolled pebbles of trap, associated with some fossiliferous stratified formation in the neighbourhood of massive trap. If the pebbles agree generally in mineral character with the latter, we are then enabled to determine its relative age by knowing that of the fossiliferous strata associated with the conglomerate. The origin of such conglomerates is explained by observing the shingle beaches composed of trap pebbles in modern volcanos, as at the base of Etna. I have already alluded (p. 508) to the formation of angular breccias or agglomerates near the mouths of craters.

Post-Tertiary volcanic rocks.—I shall now select examples of contemporaneous volcanic rocks of successive geological periods, to show that igneous causes have been in activity in all past ages of the world. They have been perpetually shifting the places where they have broken out at the earth's surface, and we can sometimes prove that those areas which are now the great theatres of volcanic action were in a state of perfect tranquillity at remote geological epochs, and that, on the other hand, in places where at former periods the most violent eruptions took place at the surface and continued for a great length of time, there has been an entire suspension of igneous action in historical times, and even as in the British Isles throughout a large part of the antecedent Tertiary Period. The most recent volcanic rocks in the British Islands are those occurring in the Hebrides and the North of Ireland, which from their intimate association with the Secondary strata were long supposed to be of contemporaneous date with them. But in 1851 the Duke of Argyll and Prof. Edward Forbes proved that a part, at least, of these old lavas were erupted during the Miocene Period. Prof. A. Geikie in 1865 discovered that none of these volcanic rocks are contemporaneous with the Secondary rocks, but that they are all of subsequent, and probably of Tertiary age ; while Mr. Judd has recently shown that they are products of three distinct periods of eruption, which with a strong show of probability may be correlated with the Eocene, Miocene, and Pliocene respectively,[1] but the denudation has been such that no cones or craters indicating the exact points of eruption have been preserved. One portion of the lavas, tuffs, and trap-dikes of Etna, Vesuvius, and the island of Ischia has been produced within the historical era ; another and a far more considerable part originated at times immediately antecedent, when the waters of the Mediterranean were already inhabited by the existing testacea, but when certain species of elephant, rhinoceros, and other quadrupeds now extinct, inhabited Europe.

Vesuvius.—I have traced in the 'Principles of Geology' the history of the changes which the volcanic region of Campania is known to have undergone during the last 2,000 years. The aggregate effect of igneous operations during that period is far from insignificant, comprising as it does the formation of the modern cone of Vesuvius since the year 79, and the production of several minor cones in Ischia, together with that of Monte Nuovo in the year 1538. Lava-currents have also flowed upon the land and along the bottom of the sea—volcanic sand, pumice, and scoriæ have been showered down so abundantly that whole cities were buried—tracts of the sea have been filled up or converted into shoals—and tufaceous sediment has been transported by rivers and land-floods to the sea. There are also proofs, during the same recent period, of a permanent alteration of the relative levels of the land and sea in several places, and of the same tract having, near Puzzuoli, been alternately upheaved and depressed to the amount of more than 20 feet. In connection with these convulsions, there are found, on the shores of the Bay of Baiæ, recent tufaceous strata, filled with articles fabricated by the hands of man, and mingled with marine shells.

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[1] Secondary Rocks of Scotland, II., Ancient Volcanoes of the Hebrides. Read at the Geol. Soc. of London, Jan. 21, 1874.

It has also been stated above (p. 188), that when we examine this same region, it is found to consist largely of tufaceous strata, of a date anterior to human history or tradition, which are of such thickness as to constitute hills from 500 to more than 2,000 feet in height. Some of these strata contain marine shells which are exclusively of living species, others contain a slight mixture, 1 or 2 per cent., of species not known as living.

The ancient part of Vesuvius is called Somma, and consists of the remains of an older cone which appears to have been partly destroyed by explosion. In the great escarpment which this remnant of the ancient mountain presents towards the modern cone of Vesuvius, there are many dikes which are for the most part vertical, and traverse the inclined beds of lava and scoriæ which were successively superimposed during those eruptions by which the old cone was formed. They project in relief several inches, or sometimes feet, from the face of the cliff, being extremely compact, and less destructible than the intersected tuffs and porous lavas. In vertical extent they vary from a few yards to 500 feet, and in breadth from 1 to 12 feet. Many of them cut all the inclined beds in the escarpment of Somma from top to bottom, others stop short before they ascend above half way. In mineral composition they scarcely differ from the lavas of Somma, the rock consisting of a base of leucite and augite, through which large crystals of augite and some of leucite are scattered.

Nothing is more remarkable than the usual parallelism of the opposite sides of the dikes, which correspond almost as regularly as the two opposite faces of a wall of masonry. This character appears at first the more inexplicable, when we consider how jagged and uneven are the rents caused by earthquakes in masses of heterogeneous composition, like those composing the cone of Somma. In explanation of this phenomenon, M. Necker refers us to Sir W. Hamilton's account of an eruption of Vesuvius in the year 1779, who records the following fact :—‘ The lavas, when they either boiled over the crater, or broke out from the conical parts of the volcano, constantly formed channels as regular as if they had been cut by art down the steep part of the mountain ; and, whilst in a state of perfect fusion, continued their course in those channels, which were sometimes full to the brim, and at other times more or less so, according to the quantity of matter in motion.

'These channels (says the same observer), I have found upon examination after an eruption, to be in general from two to five or six feet wide, and seven or eight feet deep. They were often hid from the sight by a quantity of scoriæ that had formed a crust over them ; and the lava, having been conveyed in a covered way for some yards, came out fresh again into an open channel. After an eruption, I have walked in some of those subterraneous or covered galleries, which were exceedingly curious, the sides, top, and bottom *being worn perfectly smooth and even* in most parts, by the violence of the currents of the red-hot lavas which they had conveyed for many weeks successively.' I was able to verify this phenomenon in 1858, when a stream of lava issued from a lateral cone.[1] Now, the walls of a vertical fissure, through which lava has ascended in its way to a volcanic vent, must have been exposed to the same erosion as the sides of the channels before adverted to. The prolonged and uniform friction of the heavy fluid, as it is forced and made to flow upwards, cannot fail to wear and smooth down the surfaces on which it rubs, and the intense heat must melt all such masses as project and obstruct the passage of the incandescent fluid.

The rock composing the dikes both in the modern and ancient part of Vesuvius is far more compact than that of ordinary lava, for the pressure of a column of melted matter in a fissure greatly exceeds that in an ordinary stream of lava ; and pressure checks the expansion of those gases which give rise to vesicles in lava. There is a tendency in almost all the Vesuvian dikes to divide into horizontal prisms, a phenomenon in accordance with the formation of vertical columns in horizontal beds of lava ; for in both cases the divisions which give rise to the prismatic structure are at right angles to the cooling surfaces. (See above, p. 509.)

Auvergne.—Although the latest eruptions in Central France seem to have long preceded the historical era, they are so modern as to have a very intimate connection with the present superficial outline of the country and with the existing valleys and river-courses. Among a great number of cones with perfect craters, one called the Puy de Tartaret sent forth a lava-current which can be traced up to its crater and which flowed for a distance of 13 miles along the bottom of the present valley to the village of Nechers, covering the alluvium of the old valley in which were preserved the bones of an extinct species of horse, and of a lagomys and other quadrupeds all closely allied to recent animals, while the associated land-shells were of species now living, such as *Cyclostoma elegans*, *Helix hortensis*, *H. nemoralis*, *H. lapicida*, and *Clausilia rugosa*. That the current which has issued from the Puy de Tartaret may, nevertheless, be very ancient in reference to the events of human history, we may conclude, not only from the divergence of the mammiferous fauna from that of our day, but from the fact that a Roman bridge of such form and construction as continued in use only down to the fifth century, but which may be older, is now seen at a place about a mile and a half from St. Nectaire. This ancient bridge spans the river Couze with two arches, each about 14 feet wide. These arches spring from the lava of Tartaret, on both banks, showing that a ravine precisely like that now existing, had already been excavated by the river through that lava thirteen or fourteen centuries ago.

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[1] Principles of Geology, vol. i. p. 626.

While the river Couze has in most cases, as at the site of this ancient bridge, been simply able to cut a deep channel through the lava the lower portion of which is shown to be columnar, the same torrent has in other places, where the valley was contracted to a narrow gorge, had power to remove the entire mass of basaltic rock, causing for a short space a complete breach of continuity in the volcanic current. The work of erosion has been very slow as the basalt is tough and hard, and one column after another must have been undermined and reduced to pebbles, and then to sand. During the time required for this operation, the perishable cone of Tartaret, occupying the lowest part of the great valley descending from Mount Dore and damming up the river so as to cause the Lake of Chambon, has stood uninjured, proving that no great flood or deluge can have passed over this region in the interval between the eruption of Tartaret and our own times.

Puy de Côme.—The Puy de Côme and its lava-current, near Clermont, may be mentioned as another minor volcano of about the same age. This conical hill rises from the granitic platform, at an angle of between 30° and 40°, to the height of more than 900 feet. Its summit presents two distinct craters, one of them with a vertical depth of 250 feet. A stream of lava takes its rise at the western base of the hill instead of issuing from either crater, and descends the granitic slope towards the present site of the town of Pont Gibaud. Thence it pours in a broad sheet down a steep declivity into the valley of the Sioule, filling the ancient river-channel for the distance of more than a mile. The Sioule, thus dispossessed of its bed, has worked out a fresh one between the lava and the granite of its western bank; and the excavation has disclosed, in one spot, a wall of columnar basalt about 50 feet high.[1]

The excavation of the ravine is still in progress, every winter some columns of basalt being undermined and carried down the channel of the river, and in the course of a few miles rolled to sand and pebbles. Meanwhile the cone of Côme remains unimpaired, its loose materials being protected by a dense vegetation, and the hill standing on a ridge not commanded by any higher ground, so that no floods of rain-water can descend upon it. There is no end to the waste which the hard basalt may undergo in future, if the physical geography of the country continue unchanged, no limit to the number of years during which the heap of incoherent and transportable materials called the Puy de Côme may remain in an almost stationary condition.

Puy de Pariou.—The brim of the crater of the Puy de Pariou, near Clermont, is so sharp, and has been so little blunted by time, that it scarcely affords room to stand upon. This and other cones in an equally remarkable state of integrity have stood, I conceive, uninjured, not *in spite* of their loose porous nature, as might at first be naturally supposed, but in consequence of it. No rills can collect where all the rain is instantly absorbed by the sand and scoriæ, as is remarkably the case on Etna; and nothing but a waterspout breaking directly upon the Puy de Pariou could carry away a portion of the hill, so long as it is not rent or engulphed by earthquakes.[2]

Newer Pliocene Volcanic Rocks.—The more ancient portion of Vesuvius and Etna originated at the close of the Newer Pliocene period, when less than ten, sometimes only one, in a hundred of the shells differed from those now living. In the case of Etna, it was before stated (p. 186) that Pleistocene formations occur in the neighbourhood of Catania; while the oldest lavas of the great volcano are Pliocene. These last are seen associated with sedimentary deposits at Trezza and other places on the southern and eastern flanks of the great cone.

Cyclopean Islands.—The Cyclopean Islands, called by the Sicilians Dei Faraglioni, in the sea-cliffs of which these beds of clay, lava and tuff are laid open to view, are situated in the Bay of Trezza, and may be regarded as the extremity of a promontory severed from the main land. Here numerous proofs are seen of submarine eruptions, by which the argillaceous and sandy strata were invaded and cut through, and tufaceous breccias formed. Enclosed in these breccias are many angular and hardened fragments of laminated clay in different states of alteration by heat, and intermixed with volcanic sands.

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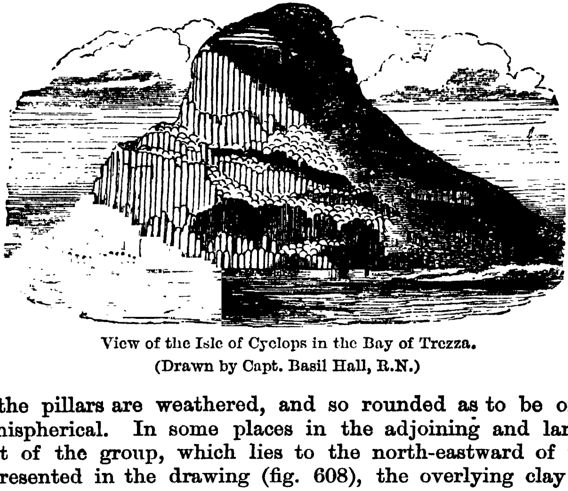
[1] Scrope's Central France, p. 60, and plate.

[2] I have elsewhere shown (Antiquity of Man, 4th ed., 1873, p. 228) that in the neighbouring district of the Velay or Haute Loire, about 50 miles S.E. of Clermont, there are proofs of the eruptions having reached down to the human, though not to the historical period.

The loftiest of the Cyclopean islets, or rather rocks, is about 200 feet in height, the summit being formed of a mass of stratified clay, the laminæ of which are occasionally subdivided by thin arenaceous layers. These strata dip to the N.W., and rest on a mass of columnar lava (see fig. 608) in which the tops of the pillars are weathered, and so rounded as to be often hemispherical. In some places in the adjoining and largest islet of the group, which lies to the north-eastward of that represented in the drawing (fig. 608), the overlying clay has been greatly altered and hardened by the igneous rock, and occasionally contorted in the most extraordinary manner; yet the lamination has not been obliterated, but, on the contrary, rendered much more conspicuous, by the indurating process.

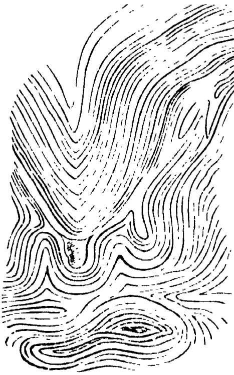
Fig. 608.



View of the Isle of Cyclops in the Bay of Trezza.
(Drawn by Capt. Basil Hall, R.N.)

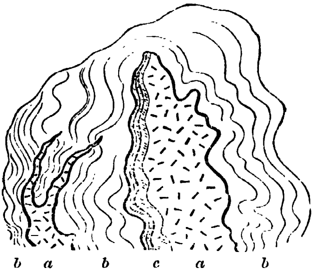
In the woodcut (fig. 609), I have represented a portion of the altered rock, a few feet square, where the alternating thin laminæ of sand and clay are contorted in a manner often observed in ancient metamorphic schists. A great fissure, running from east to west, nearly divides this larger island into two parts, and lays open its internal structure. In the section thus exhibited, a dike of lava is seen, first cutting through an older mass of lava, and then penetrating the superincumbent tertiary strata. In one place the lava ramifies and terminates in thin veins, from a few feet to a few inches in thickness (see fig. 610). The arenaceous laminæ are much hardened at the point of contact, and the clays are converted into siliceous schist. In this island the altered rocks assume a honeycomb structure on their weathered surface, singularly contrasted with the smooth and even outline which the same beds present in their usual soft and yielding state.

Fig. 609.



Contortions of strata in the largest of the Cyclopean Islands.

Fig. 610.



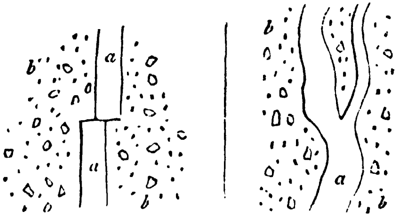
Newer pliocene strata invaded by lava, Isle of Cyclops (horizontal section).

a. Lava. *b.* Laminated clay and sand. *c.* The same altered.

Dikes of Palagonia.—Dikes of vesicular and amygdaloidal lava are also seen traversing marine tuff or peperino, west of Palagonia, some of the pores of the lava being empty, while others are filled with carbonate of lime. In such cases we may suppose the tuff to have resulted from showers of volcanic sand and scoriæ, together with fragments of limestone, thrown out by a submarine explosion similar to that which gave rise to Graham Island in 1831. When the mass was, to a certain degree, consolidated, it may have been rent open, so that the lava ascended through fissures, the walls of which were perfectly even and parallel. In one case after the melted matter that filled the rent (fig. 611) had cooled down, it must have been fractured and shifted horizontally by a lateral movement.

In the second figure (fig. 612), the lava has more the appearance of a vein, which forced its way through the peperino. It is highly probable that similar appearances would be seen, if we could examine the floor of the sea in that part of the Mediterranean where the waves have recently washed away the new volcanic island ; for when a superincumbent mass of ejected fragments has been removed by denudation, we may expect to see sections of dikes traversing tuff, or, in other words, sections of the channels of communication by which the subterranean lavas reached the surface.

Fig. 611. Fig. 612.



Ground-plan of dikes near Palagonia.

a. Lava. *b.* Peperino, consisting of volcanic sand, mixed with fragments of lava and limestone.

Madeira.—Although the more ancient portion of the volcanic eruptions by which the island of Madeira and the neighbouring one of Porto Santo were built up occurred, as we shall presently see, in the Upper Miocene period, a still larger part of the island is of Pliocene date. That the latest outbreaks belonged to the Newer Pliocene Period, I infer from the close affinity to the present flora of Madeira of the fossil plants preserved in a leaf-bed in the north-eastern part of the island. These fossils associated with some lignite in the ravine of the river San Jorge, can none of them be proved to be of extinct species, but their antiquity may be inferred from the following considerations. Firstly—The leaf-bed, discovered by Mr. Hartung and myself in 1853, at the height of 1,000 feet above the level of the sea, crops out at the base of a cliff formed by the erosion of a gorge, cut through alternating layers of basalt and scoriæ, the product of a vast succession of eruptions of unknown date, piled up to a thickness of 1,000 feet, and which were all poured out after the plants, of which about 20 species have been recognised, flourished in Madeira. These lavas are inclined at an angle of about 15° to the north, and came down from the great central region of eruption. Their accumulation implies a long period of intermittent volcanic action, subsequently to which the ravine of San Jorge was hollowed out. Secondly—Some few of the plants, though perhaps all of living genera, are supposed to be of species not now existing in the island. They have been described by Sir Charles Bunbury and Professor Heer, and the former first pointed out that many of the leaves are of the laurel type and analogous to those now flourishing in the modern forests of Madeira. He also recognised among them the leaves of *Woodwardia radicans*, and *Davallia Canariensis*, ferns now abundant in Madeira. Thirdly—The great age of this leaf-bed of San Jorge, which was perhaps originally formed in the crater of some ancient volcanic cone afterwards buried under lava, is proved by its belonging to a part of the eastern extremity of Madeira, which, after the close of the igneous eruptions, became covered in the adjoining district of Caniçal with blown sand in which a vast number of land shells were buried. These fossil shells belonged to no less than 36 species, among which are many now extremely rare in the island, and others, about 5 per cent., extinct or unknown in any part of the world. Several of these of the genus *Helix* are conspicuous from the peculiarity of their forms, others from their large dimensions. The geographical configuration of the country shows that this shell-bed is considerably more modern than the leaf-bed, it must therefore be referred to the Newer Pliocene according to the definition of this period given in a former chapter (p. 120).

Older Pliocene Period.—*Italy.*—In Tuscany, as at Radicofani, Viterbo, and Aquapendente, and in the Campagna di Roma, submarine volcanic tuffs are interstratified with the Older Pliocene strata of the Subapennine hills in such a manner as to leave no doubt that they were the products of eruptions which occurred when the shelly marls and sands of the Subapennine hills were in the course of deposition. This opinion I expressed[1] after my visit to Italy in 1828, and it was confirmed in 1850 by the arguments adduced by Sir R. Murchison in favour of the submarine origin of the Tertiary volcanic rocks of Italy.[2] These rocks are well known to rest conformably on the Subapennine marls, even as far south as Monte Mario in the suburbs of Rome. On the exact age of the deposits of Monte Mario new light has recently been thrown by a careful study of their marine fossil shells, undertaken by MM. Rayneval, Vanden Hecke, and Ponzi. They have compared no less than 160 species with the shells of the Coralline Crag of Suffolk, so well described by Mr. Searles Wood; and the specific agreement between the British and Italian fossils is so great, if we make due allowance for geographical distance and the difference of latitude, that we can have little hesitation in referring both to the same period, or to the Older Pliocene of this work. It is highly probable that, between the oldest trachytes of Tuscany and the newest rocks in the neighbourhood of Naples, a series of volcanic products might be detected of every age from the Older Pliocene to the historical epoch.

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[1] See 1st edit. of Principles of Geology, vol. iii. chaps. xiii. and xiv. 1833; and former edits. of this work, chap. xxxi.

[2] Geol. Quart. Journ., vol. vi. p 281.

Pliocene Volcanos of the Eifel.—Some of the most perfect cones and craters in Europe, not even excepting those of the district round Vesuvius, may be seen on the left or west bank of the Rhine, near Bonn and Andernach. They exhibit characters distinct from any which I have observed elsewhere, owing to the large part which the escape of aqueous vapour has played in the eruptions and the small quantities of lava emitted. The fundamental rocks of the district are grey and red sandstones and shales, with some associated limestones, replete with fossils of the Devonian or Old Red Sandstone group. The volcanos broke out in the midst of these inclined strata, and when the present systems of hills and valleys had already been formed. The eruptions occurred sometimes at the bottom of deep valleys, sometimes on the summit of hills, and frequently on intervening platforms. In travelling through this district we often come upon them most unexpectedly, and may find ourselves on the very edge of a crater before we had been led to suspect that we were approaching the site of any igneous outburst. Thus, for example, on arriving at the village of Gemund, immediately south of Daun, we leave the stream, which flows at the bottom of a deep valley in which strata of sandstone and shale crop out. We then climb a steep hill, on the surface of which we see the edges of the same strata dipping inwards towards the mountain. When we have ascended to a considerable height, we see fragments of scoriæ sparingly scattered over the surface; until, at length, on reaching the summit, we find ourselves suddenly on the edge of a *tarn*, or deep circular lake-basin called the Gemunder Maar. In it we recognise the ordinary form of a crater, for which we have been prepared by the occurrence of scoriæ scattered over the surface of the soil. But on examining the walls of the crater we find precipices of sandstone and shale which exhibit no signs of the action of heat; and we look in vain for those beds of lava and scoriæ, dipping outwards on every side, which we have been accustomed to consider as characteristic of volcanic vents. As we proceed, however, to the opposite side of the lake, we find a considerable quantity of scoriæ and some lava, and see the whole surface of the soil sparkling with volcanic sand, and strewed with ejected fragments of half-fused shale, which preserves its laminated texture in the interior, while it has a vitrified or scoriform coating.

Other crater-lakes of circular or oval form, and hollowed out of similar ancient strata, occur in the Upper Eifel, where copious aëriform discharges have taken place throwing out vast heaps of pulverised shale into the air. I know of no other extinct volcanos where gaseous explosions of such magnitude have been attended by the emission of so small a quantity of lava. Yet I looked in vain in the Eifel for any appearances which could lend support to the hypothesis that the sudden rushing out of such enormous volumes of gas had ever lifted up the stratified rocks immediately around the vent, so as to form conical masses, having their strata dipping outwards on all sides from a central axis, as is assumed in the theory of elevation craters, alluded to in the last chapter.

I have already given (p. 511, fig. 600) an example in the Eifel of a small stream of lava which issued from one of the craters of that district at Bertrich-Baden. It shows that when some of these volcanos were in action the valleys had already been eroded to their present depth.

Trass.—The tufaceous alluvium called *trass*, which has covered large areas in the Eifel, and choked up some valleys now partially re-excavated, is unstratified. Its base consists almost entirely of pumice, in which are included fragments of basalt, and other lavas, pieces of burnt shale, slate, and sandstone, and numerous trunks and branches of trees. If, as is probable, this trass was formed during the period of volcanic eruptions, it may have originated in the manner of the moya of the Andes.

We may easily conceive that a similar mass might now be produced, if a copious evolution of gases should occur in one of the lake-basins. If a breach should be made in the side of the cone, the flood would sweep away great heaps of ejected fragments of shale and sandstone, which would be borne down into the adjoining valleys. Forests might be torn up by such a flood, and thus the occurrence of the numerous trunks of trees dispersed irregularly through the trass, can be explained. The manner in which this trass conforms to the shape of the present valleys implies its comparatively modern origin, probably one dating farther back than the Pliocene period.

CHAPTER XXX.

AGE OF VOLCANIC ROCKS—*continued.*

Volcanic rocks of the Upper Miocene Period—Madeira—Grand Canary—Azores—Lower Miocene Volcanic rocks—Isle of Mull—Staffa and Antrim—The Eifel—Upper and Lower Miocene Volcanic rocks of Auvergne—Hill of Gergovia—Eocene Volcanic rocks of the Hebrides—Of Monte Bolca—Trap of Cretaceous period—Oolitic Period—Triassic Period—Permian Period—Carboniferous Period—Erect trees buried in Volcanic Ash in the Island of Arran—Old Red Sandstone Period—Silurian Period—Cambrian Period—Laurentian Volcanic rocks.

Volcanic rocks of the Upper Miocene Period.—*Madeira.*—The greater part of the volcanic eruptions of Madeira, as we have already seen, p. 532, belong to the Pliocene period, but the most ancient of them are of Upper Miocene date, as shown by the fossil shells included in the marine tuffs which have been upraised at San Vicente in the northern part of the island to the height of 1,300 feet above the level of the sea. A similar marine and volcanic formation constitutes the fundamental portion of the neighbouring island of Porto Santo, forty miles distant from Madeira, and is there elevated to an equal height, and covered, as in Madeira, with lavas of sub-aërial origin.

The largest number of fossils have been collected from the tuffs and conglomerates and some beds of limestone in the island of Baixo off the southern extremity of Porto Santo. They amount in this single locality to more than sixty in number, of which about fifty are mollusca, but many of these are only casts. Some of the shells probably lived on the spot during the intervals between eruptions, and some may have been cast up into the water or air together with muddy ejections, and, falling down again, have been deposited on the bottom of the sea. The hollows in some of the fragments of vesicular lava, of which the breccias and conglomerates are composed, are partially filled with calc-sinter, being thus half converted into amygdaloids. Among the fossil shells common to Madeira and Porto Santo, large cones, strombs, and cowries are conspicuous among the univalves, and *Cardium*, *Spondylus*, and *Lithodomus* among the lamellibranchiate bivalves, and among the *Echinoderms* the large Clypeaster called *C. altus*, an extinct European Miocene fossil.

The largest list of fossils has been published by Mr. Karl Mayer, in Hartung's 'Madeira;' but in the collection made by myself, and in a still larger one formed by Mr. J. Yate Johnson, several remarkable forms not in Mayer's list occur, as, for example, *Pholadomya*, and a large *Terebra*. Mr. Johnson also found a fine specimen of *Nautilus* (*Aturia*) *ziczac* (fig. 214, p. 249), a well-known Falunian and Eocene fossil of Europe; and in the same volcanic tuff of Baixo, the Echinoderm *Brissus Scillæ*, a living Mediterranean species, found fossil in the Miocene strata of Malta. Mr. Mayer identifies one third of the Madeira shells with known European Miocene (or Falunian) forms. The huge Strombus of San Vicente and Porto Santo, *S. Italicus*, is an extinct shell of the Subapennine or Older Pliocene formations. The mollusca already obtained from various localities of Madeira and Porto Santo are not less than one hundred in number, and, according to the late Dr. S. P. Woodward, rather more than a third are of species still living, but many of these are not now inhabitants of the neighbouring sea.

It has been remarked (p. 194) that in the Older Pliocene and Upper Miocene deposits of Europe, many forms occur of a more southern aspect than those now inhabiting the nearest sea. In like manner the fossil corals, or Zoantharia, six in number, which I obtained from Madeira, of the genera *Astræa*, *Sarcinula*, *Hydnophora*, were pronounced by Mr. Lonsdale to be forms foreign to the adjacent coasts, and agreeing with the fauna of a sea warmer than that now separating Madeira from the nearest part of the African coast. We learn, indeed, from the observations made in 1859, by the Rev. R. T. Lowe, that more than one half, or fifty-three in ninety, of the marine mollusca collected by him from the sandy beach of Mogador are common British species, although Mogador is 18½ degrees south of the nearest shores of England. The living shells of Madeira and Porto Santo are in like manner those of a temperate climate, although in great part differing specifically from those of Mogador.[1]

Grand Canary.—In the Canaries,[2] especially in the Grand Canary, the same marine Upper Miocene formation is found. Stratified tuffs, with intercalated conglomerates and lavas, are there seen in nearly horizontal layers in sea-cliffs about 300 feet high, near Las Palmas. Mr. Hartung and I were unable to find marine shells in these tuffs at a greater elevation than 400 feet above the sea; but as the deposit to which they belong reaches to the height of 1,100 feet or more in the interior, we conceive that an upheaval of at least that amount has taken place. The *Clypeaster altus*, *Spondylus gæderopus*, *Pectunculus pilosus*, *Cardita calyculata*, and several other shells, serve to identify this formation with that of the Madeiras, and *Ancillaria glandiformis*, which is not rare, and some other fossils, remind us of the faluns of Touraine.

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[1] Linnean Proceedings; Zoology, 1860.

[2] For a complete description of the volcanic island of Palma, one of the Canary Islands, see Elements of Geology, 1865, p. 621.

The sixty-two Miocene species which I collected in the Grand Canary were referred, by the late Dr. S. P. Woodward, to forty-seven genera, ten of which are no longer represented in the neighbouring sea, namely *Corbis*, an African form, *Hinnites*, now living in Oregon, *Thecidium* (*T. Mediterraneum*, identical with the Miocene fossil of St. Juvat, in Brittany), *Calyptræa*, *Hipponyx*, *Nerita*, *Erato*, *Oliva*, *Ancillaria*, and *Fasciolaria*.

These tuffs of the southern shores of the Grand Canary, containing the Upper Miocene shells, appear to be about the same age as the most ancient volcanic rocks of the island. Over the marine lavas and tuffs trachytic and basaltic products of subaërial volcanic origin, between 4,000 and 5,000 feet in thickness, have been piled, the central parts of the Grand Canary reaching the height of about 6,000 feet above the level of the sea. A large portion of this mass is of Pliocene date, and some of the latest lavas have been poured out since the time when the valleys were already excavated to within a few feet of their present depth.

On the whole the rocks of the Grand Canary, an island of a nearly circular shape, and 6½ geographical miles diameter, exhibit proofs of a long series of eruptions beginning like those of Madeira, Porto Santo, and the Azores, in the Upper Miocene period, and continued to the Pleistocene Period. The building up of the Grand Canary by subaërial eruptions, several thousand feet thick, went on simultaneously with the gradual upheaval of the earliest products of submarine eruptions, in the same manner as the Pliocene marine strata of the oldest parts of Vesuvius and Etna have been upraised during eruptions of Post-tertiary date.

In proof that movements of elevation have actually continued down to Post-tertiary times, I may remark that I found raised beaches containing shells of the Recent Period in the Grand Canary, Teneriffe, and Porto Santo. The most remarkable raised beach which I observed in the Grand Canary, in the study of which I was assisted by Don Pedro Maffiotte, is situated in the north-eastern part of the island at San Catalina about a quarter of a mile north of Las Palmas. It intervenes between the base of the high cliff formed of the tuffs with Miocene shells and the sea shore. From this beach, at an elevation of twenty-five feet above high-water mark, and at a distance of about 150 feet from the present shore, I obtained more than fifty species of living marine shells. Many of them, according to Dr. S. P. Woodward, are no longer inhabitants of the contiguous sea, as, for example, *Strombus bubonius*, which is still living on the West Coast of Africa, *Cerithium procerum*, found at Mozambique; others are Mediterranean species, as *Pecten Jacobæus* and *P. polymorphus*. Some of these testacea, such as *Cardita squamosa*, are inhabitants of deep water, and the deposit on the whole seems to indicate a depth of water exceeding a hundred feet.

Azores.—In the island of St. Mary's, one of the Azores, marine fossil shells have long been known. They are found on the north-east coast on a small projecting promontory called Ponta do Papagaio (or Point-Parrot), chiefly in a limestone about 20 feet thick, which rests upon, and is again covered by, basaltic lavas, scoriæ, and conglomerates. The pebbles in the conglomerate are cemented together with carbonate of lime.

Mr. Hartung, in his account of the Azores, published in 1860, describes twenty-three shells from St. Mary's,[1] of which eight perhaps are identical with living species, and twelve are with more or less certainty referred to European Tertiary forms, chiefly Upper Miocene. One of the most characteristic and abundant of the new species, *Cardium Hartungi*, not known as fossil in Europe, is very common in Porto Santo and Baixo, and serves to connect the Miocene fauna of the Azores and the Madeiras. In some of the Azores, as well as in the Canary islands, the volcanic fires are not yet extinct, as the recorded eruptions of Lanzerote, Teneriffe, Palma, St. Michael's, and others attest. The late soundings (1873) of H.M.S. Challenger have shown the Azores, Canaries, Cape de Verde islands, &c., to be merely the highest summits of a great submerged mountain ridge, comparable with the Andes of South America both in extent and altitude, as well as in the volcanic character of many of its most elevated peaks.

Lower Miocene volcanic rocks—*Isle of Mull and Antrim.*—I may refer the reader to the account already given (p. 230) of leaf-beds at Ardtun, in the Isle of Mull in the Hebrides, which bear a relation to the associated volcanic rocks of Lower Miocene date analogous to that which the Madeira leaf-bed, above described (p. 532), bears to the Pliocene lavas of that island. At Ballypalidy and Shane's Castle in the County of Antrim, similar plants of Miocene species have been found in beds intercalated with the basalts; and both in Antrim and Mull the basalts are seen to lie unconformably upon the highest strata of the Chalk. The Miocene basaltic lavas constitute great plateaux, which must originally have covered many thousands of square miles, though now broken up by denudation into a number of disconnected fragments; the lavas are often piled upon one another to a thickness of more than 2,000 feet.[1] The interesting features displayed by these basalts at the Giant's Causeway in Antrim and at Fingal's Cave in the Isle of Staffa are too well known to require description.

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[1] Hartung, Die Azoren, 1860; also Insel Gran Canaria, Madeira und Porto Santo, 1864, Leipsig.

The Eifel.—A large portion of the volcanic rocks of the Lower Rhine and the Eifel are coeval with the Lower Miocene deposits to which most of the 'Brown-Coal' of Germany belongs. The Tertiary strata of that age are seen on both sides of the Rhine, in the neighbourhood of Bonn, resting unconformably on highly inclined and vertical strata of Silurian and Devonian rocks. The Brown-Coal formation of that region consists of beds of loose sand, sandstone, and conglomerate, clay with nodules of clay-ironstone, and occasionally silex. Layers of light brown, and sometimes black lignite are interstratified with the clays and sands, and often irregularly diffused through them. They contain numerous impressions of leaves and stems of trees, and are extensively worked for fuel, whence the name of the formation. In several places, layers of trachytic tuff are interstratified, and in these tuffs are leaves of plants identical with those found in the brown-coal, showing that, during the period of the accumulation of the latter, some volcanic products were ejected. The igneous rocks of the Westerwald, and of the mountains called the Siebengebirge, consist partly of basaltic and partly of trachytic lavas, the latter being in general the more ancient of the two. There are many varieties of trachyte, some of which are highly crystalline, resembling a coarse-grained granite, with large separate crystals of felspar. Trachytic tuff is also very abundant.

M. Von Dechen, in his work on the Siebengebirge,[2] has given a copious list of the animal and vegetable remains of the fresh-water strata associated with the brown-coal of that part of Germany. Plants of the genera *Flabellaria*, *Ceanothus*, and *Daphnogene*, including *D. cinnamomifolia* (fig. 158, p. 221), occur in these beds, with nearly 150 other plants. The fishes of the brown-coal near Bonn are found in a bituminous shale, called paper-coal, from being divisible into extremely thin leaves. The individuals are very numerous; but they appear to belong to a small number of species, some of which were referred by Agassiz to the genera *Leuciscus*, *Aspius*, and *Perca*. The remains of frogs also, of extinct species, have been discovered in the paper-coal; and a complete series may be seen in the museum at Bonn, from the most imperfect state of the tadpole to that of the full-grown animal. With these a salamander, scarcely distinguishable from the recent species, has been found, and the remains of many insects.

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[1] Judd, 'Ancient Volcanoes of the Highlands,' Geol. Soc., Jan. 21, 1874.

[2] Geognost. Beschreib. des Siebengebirges am Rhein. Bonn, 1852.

Upper and Lower Miocene volcanic rocks of Auvergne.—The extinct volcanos of Auvergne and Cantal in Central France, seem to have commenced their eruptions in the Lower Miocene period, but to have been most active during the Upper Miocene and Pliocene eras. I have already alluded to the grand succession of events, of which there is evidence in Auvergne since the last retreat of the sea (see p. 527).

The earliest monuments of the Tertiary period in that region are lacustrine deposits of great thickness, in the lowest conglomerates of which are rounded pebbles of quartz, mica-schist, granite, and other non-volcanic rocks, without the slightest intermixture of igneous products. To these conglomerates succeed argillaceous and calcareous marls and limestones, containing Lower Miocene shells and bones of mammalia, the higher beds of which sometimes alternate with volcanic tuff of contemporaneous origin. After the filling up or drainage of the ancient lakes, huge piles of trachytic and basaltic rocks, with volcanic breccias, accumulated to a thickness of several thousand feet, and were superimposed upon granite, or the contiguous lacustrine strata. The greater portion of these igneous rocks appear to have originated during the Upper Miocene and Pliocene periods; and extinct quadrupeds of those eras, belonging to the genera Mastodon, Rhinoceros, and others, were buried in ashes and beds of alluvial sand and gravel, which owe their preservation to overspreading sheets of lava.

In Auvergne, the most ancient and conspicuous of the volcanic masses is Mont Dore, which rests immediately on the granitic rocks standing apart from the freshwater strata. This great mountain rises suddenly to the height of several thousand feet above the surrounding platform, and retains the shape of a flattened and somewhat irregular cone, the slope of which is gradually lost in the high plain around. This cone is composed of layers of scoriæ, pumice-stones, and their fine detritus, with interposed beds of trachyte and basalt, which descend often in uninterrupted sheets until they reach and spread themselves round the base of the mountain.[1] Conglomerates, also, composed of angular and rounded fragments of igneous rocks, are observed to alternate with the above: and the various masses are seen to dip off from the central axis, and to lie parallel to the sloping flanks of the mountain. The summit of Mont Dore terminates in seven or eight rocky peaks, where no regular crater can now be traced, but where we may easily imagine one to have existed, which may have been shattered by earthquakes, and have suffered degradation by aqueous agents. Originally, perhaps, like the highest crater of Etna, it may have formed an insignificant feature in the great pile, and, like it, may frequently have been destroyed and renovated.

Respecting the age of the great mass of Mont Dore, we cannot come at present to any positive decision, because no organic remains have yet been found in the tuffs, except impressions of the leaves of trees of species not yet determined. It has already been stated (p. 217) that the earliest eruptions must have been posterior in origin to those grits and conglomerates of the freshwater formation of the Limagne which contain no pebbles of volcanic rocks. But there is evidence at a few points, as in the hill of Gergovia, presently to be mentioned, that some eruptions took place before the great lakes were drained, while others occurred after the desiccation of those lakes, and when deep valleys had already been excavated through freshwater strata.

The valley in which the cone of Tartaret, above mentioned (p. 528), is situated affords an impressive monument of the very different dates at which the igneous eruptions of Auvergne have happened; for while the cone itself is of Pleistocene date, the valley is bounded by lofty precipices composed of sheets of ancient columnar trachyte and basalt, which once flowed from the summit of Mont Dore in some part of the Miocene period. These Miocene lavas had accumulated to a thickness of nearly 1,000 feet before the ravine was cut down to the level of the river Couze, a river which was at length dammed up by the modern cone and the upper part of its course transformed into a lake.

Gergovia.—It has been supposed by some observers that there is an alternation of a contemporaneous sheet of lava with freshwater strata in the hill of Gergovia near Clermont. But this idea has arisen from the intrusion of the dike represented in the annexed diagram (fig. 613), which has altered the green and white marls both above and below. Nevertheless, there is a real alternation of volcanic tuff with strata containing Lower Miocene freshwater shells, among others a Melania allied to *M. inquinata* (fig. 220, p. 251), with a Melanopsis and a Unio ; there can, therefore, be no doubt that in Auvergne some volcanic explosions took place before the drainage of the lakes, and at a time when the Lower Miocene species of animals and plants still flourished.

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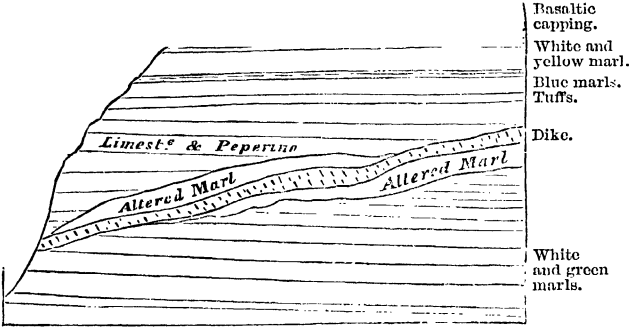
[1] Scrope's Central France, p. 98.

Fig. 613.



Hill of Gergovia.

Eocene Volcanic Rocks.—*Hebrides.*—It has been shown by Mr. Judd [1] that before the eruption of the Miocene basalts of the Hebrides, great masses of felspathic lavas were poured out from the same vents. But while the basaltic class of lavas spread over vast areas and extended to distances of even 50 or 60 miles from their points of origin, the felspathic lavas have accumulated around the vents themselves, and are usually confined to distances of about 10 miles from them ; the same differences in the mode of behaviour of streams composed of lavas of the basaltic and felspathic varieties respectively, have been pointed out by Mr. Scrope and other authors in the case of many recent volcanos. From the fact that while on the one hand igneous activity appears to have commenced in the district before the close of the Cretaceous epoch, and on the other that the Miocene basalts lie unconformably upon the earlier felspathic lavas, Mr. Judd is led to regard these latter as representative in a general manner of the Eocene period.

Monte Bolca.—The fissile limestone of Monte Bolca, near Verona, has for many centuries been celebrated in Italy for the number of perfect Ichthyolites which it contains. Agassiz has described no less than 133 species of fossil fish from this single deposit, and the multitude of individuals by which many of the species are represented, is attested by the variety of specimens treasured up in the principal museums of Europe. They have been all obtained from quarries worked exclusively by lovers of natural history, for the sake of the fossils. Had the lithographic stone of Solenhofen, now regarded as so rich in fossils, been in like manner quarried solely for scientific objects, it would have remained almost a sealed book to paleontologists, so sparsely are the organic remains scattered through it. When I visited Monte Bolca, in company with Sir Roderick Murchison, in 1828, we ascertained that the fish-bearing beds were of Eocene date, containing well-known species of Nummulites, and that a long series of submarine volcanic eruptions, evidently contemporaneous, had produced beds of tuff, which are cut through by dikes of basalt. There is evidence here of a long series of submarine volcanic eruptions of Eocene date, and during some of them, as Sir R. Murchison has suggested, shoals of fish were probably destroyed by the evolution of heat, noxious gases, and tufaceous mud, just as happened when Graham's Island was thrown up between Sicily and Africa in 1831, at which time the waters of the Mediterranean were seen to be charged with red mud, and covered with dead fish over a wide area.[1]

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[1] Ancient Volcanos of the Highlands, Quart. Geol. Journ., 1874.

Associated with the marls and limestones of Monte Bolca are beds containing lignite and shale with numerous plants, which have been described by Unger and Massalongo, and referred by them to the Eocene period. I have already cited (p. 246) Professor Heer's remark, that several of the species are common to Monte Bolca and the white clay of Alum Bay, a Middle Eocene deposit; and the same botanist dwells on the tropical character of the flora of Monte Bolca and its distinctness from the subtropical flora of the Lower Miocene of Switzerland and Italy, in which last there is a far more considerable mixture of forms of a temperate climate, such as the willow, poplar, birch, elm, and others. That scarcely any one of the Monte Bolca fish should have been found in any other locality in Europe, is a striking illustration of the extreme imperfection of the paleontological record. We are in the habit of imagining that our insight into the geology of the Eocene period is more than usually perfect, and we are certainly acquainted with an almost unbroken succession of assemblages of shells passing one into the other from the era of the Thanet sands to that of the Bembridge beds or Paris gypsum. The general dearth, therefore, of fish in the different members of the Eocene series, Upper, Middle, and Lower, might induce a hasty reasoner to conclude that there was a poverty of ichthyic forms during this period; but when a local accident, like the volcanic eruptions of Monte Bolca, occurs, proofs are suddenly revealed to us of the richness and variety of this great class of vertebrata in the Eocene sea. The number of genera of Monte Bolca fish is, according to Agassiz, no less than seventy-five, twenty of them peculiar to that locality, and only eight common to the antecedent Cretaceous period. No less than forty-seven out of the seventy-five genera make their appearance for the first time in the Monte Bolca rocks, none of them having been met with as yet in the antecedent formations. They form a great contrast to the fish of the secondary strata, as, with the exception of the Placoids, they are all Teleosteans, only one genus, *Pycnodus*, belonging to the order of Ganoids, which form, as before stated, the vast majority of the ichthyolites entombed in the secondary or Mesozoic rocks.

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[1] Principles of Geology, chap. xxvii., 11th ed.

Cretaceous Period.—M. Virlet, in his account of the geology of the Morea, p. 205, has clearly shown that certain traps in Greece are of Cretaceous date; as those, for example, which alternate conformably with cretaceous limestone and greensand between Kastri and Damala in the Morea. They consist in great part of diallage rocks and serpentine, and of an amygdaloid with calcareous kernels, and a base of serpentine. In certain parts of the Morea, the age of these volcanic rocks is established by the following proofs: first, the lithographic limestones of the Cretaceous era are cut through by trap, and then a conglomerate occurs, at Nauplia and other places, containing in its calcareous cement many well-known fossils of the chalk and greensand, together with pebbles formed of rolled pieces of the same serpentinous trap, which appear in the dikes above alluded to.

Period of Oolite and Lias.—Although the green and serpentinous trap rocks of the Morea belong chiefly to the Cretaceous era, as before mentioned, yet it seems that some eruptions of similar rocks began during the Oolitic period;[1] and it is probable that a large part of the trappean masses, called ophiolites in the Apennines, and associated with the limestone of that chain, are of corresponding age.

Trap of the New Red Sandstone Period.—In the southern part of Devonshire, trappean rocks are associated with New Red Sandstone, and, according to Sir H. De la Beche, have not been intruded subsequently into the sandstone, but were pro-

[1] Boblaye and Virlet, Morea, p. 23.

duced by contemporaneous volcanic action. Some beds of grit, mingled with ordinary red marl, resemble sands ejected from a crater; and in the stratified conglomerates occurring near Tiverton are many angular fragments of trap porphyry, some of them one or two tons in weight, intermingled with pebbles of other rocks. These angular fragments were probably thrown out from volcanic vents, and fell upon sedimentary matter then in the course of deposition.[1]

Trap of the Permian Period.—The recent investigations of Mr. Archibald Geikie in Ayrshire and at Nithsdale in Dumfriesshire have shown that some of the volcanic rocks in that county are of Permian age, and it appears highly probable that the uppermost portion of Arthur's Seat in the suburbs of Edinburgh marks the site of an eruption of the same era.

Trap of the Carboniferous Period.—Two extensive developments of trap rocks occur in the carboniferous basin of the Forth in Scotland. One of these is well exhibited along the shores of Fifeshire, where the igneous masses consist of basalt, sometimes with olivine, and of dolerites. These appear to have been erupted while the sedimentary strata were in a horizontal position, and to have suffered the same dislocations which those strata have subsequently undergone. In the associated volcanic tuffs of this age are found, not only fragments of limestone, shale, flinty slate, and sandstone, but also pieces of coal. Other traps connected with the carboniferous formation may be traced along the south margin of Stratheden, and constitute a ridge parallel with the Ochils, extending from Stirling to near St. Andrews. These consist almost exclusively of dolerite, becoming, in a few instances, earthy and amygdaloidal. They are either interbedded with, or intruded among the sandstone, shale, limestone and ironstone of the Lower Carboniferous. I examined these trap rocks in 1838, in the cliffs south of St. Andrews, where they consist in great part of stratified tuffs, which are curved, vertical, and contorted, like the associated coal-measures. In the tuff I found fragments of carboniferous shale and limestone, and intersecting veins of dolerite.

Fife—Flisk dike.—A trap dike was pointed out to me by Dr. Fleming, in the parish of Flisk, in the northern part of the county of Fife, which cuts through the grey sandstone and shale, forming the lowest part of the Old Red Sandstone, but which may probably be of carboniferous date. It may be traced for many miles, passing through the amygdaloidal and other traps of the hill called Norman's Law in that parish.

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[1] De la Beche, Geol. Proceedings, vol. ii. p. 198.

In its course it affords a good exemplification of the passage from the trappean into the plutonic, or highly crystalline texture. Professor Gustav Rose, to whom I submitted specimens of this dike, found it to be dolerite, and composed of greenish black augite and Labrador felspar, the latter being the most abundant ingredient. A small quantity of magnetic iron, perhaps titaniferous, is also present. The result of this analysis is interesting, because both the ancient and modern lavas of Etna consist in like manner of augite, Labradorite, and titaniferous iron.

Erect trees buried in volcanic ash at Arran.—An interesting discovery was made in 1867 by Mr. E. A. Wünsch in the lower carboniferous strata of the north-eastern part of the island of Arran. In the sea-cliff about five miles north of Corrie, near the village of Laggan, strata of volcanic ash occur, forming a solid rock cemented by carbonate of lime and enveloping trunks of trees, determined by Mr. Binney to belong to the genera Sigillaria and Lepidodendron. Some of these trees are at right angles to the planes of stratification, while others are prostrate and accompanied by leaves and fruits of the same genera. I visited the spot in company with Mr. Wünsch in 1870, and saw that the trees with their roots, of which about fourteen had been observed, occur at two distinct levels in volcanic tuffs parallel to each other, and inclined at an angle of about 40°, having between them beds of shale and coaly matter seven feet thick. It is evident that the trees were overwhelmed by a shower of ashes from some neighbouring volcanic vent, as Pompeii was buried by matter ejected from Vesuvius. The trunks, several of them from three to five feet in circumference, remained with their Stigmarian roots spreading through the stratum below, which had served as a soil. The trees must have continued for years in an upright position after they were killed by the shower of burning ashes, giving time for a partial decay of the interior, so as to afford hollow cylinders into which the spores of plants were wafted. These spores germinated and grew, until finally their stems were petrified by carbonate of lime like some of the remaining portions of the wood of the containing Sigillaria. Mr. Carruthers has discovered that sometimes the plants which had thus grown and become fossil in the inside of a single trunk belonged to several distinct genera. The fact that the tree-bearing deposits now dip at an angle of 40° is the more striking as they must clearly have remained horizontal and undisturbed during a long period of intermittent and contemporaneous volcanic action.

In some of the associated carboniferous shales, ferns and

Trap of the Old Red Sandstone Period.—By referring to the section explanatory of the structure of Forfarshire, already given (p. 51), the reader will perceive that beds of conglomerate, No. 3, occur in the middle of the Old Red Sandstone system, 1, 2, 3, 4. The pebbles in these conglomerates are sometimes composed of gneiss and quartzose rocks, sometimes exclusively of different varieties of trap, which last, although purposely omitted in the section referred to, is often found either intruding itself in amorphous masses and dikes into the old fossiliferous tilestones, No. 4, or alternating with them in conformable beds. All the different divisions of the red sandstone, 1, 2, 3, 4, are occasionally intersected by dikes, but they are very rare in Nos. 1 and 2, the upper members of the group consisting of red shale and red sandstone. These phenomena, which occur at the foot of the Grampians, are repeated in the Sidlaw Hills ; and it appears that in this part of Scotland volcanic eruptions were most frequent in the earlier part of the Old Red Sandstone period. These lavas are for the most part of the felspathic class, their structure being sometimes porphyritic, at others amygdaloidal ; in the latter case the kernels of the latter being sometimes calcareous, often calcedonic, and forming beautiful agates. In a more or less decomposed condition these felspathic lavas are known under the name of claystones. With them occur beds of stratified tuff and conglomerate, stone, compact felspar, and tuff. Some of these rocks look as if they had flowed as lavas over the bottom of the sea, and enveloped quartz pebbles which were lying there, so as to form conglomerates with a base of greenstone, as is seen in Lumley Den, in the Sidlaw Hills. On either side of the axis of this chain of hills (see section, p. 51), the beds of massive trap, and the tuffs composed of volcanic sand and ashes, dip regularly to the south-east or north-west, conformably with the shales and sandstones.

But the geological structure of the Pentland Hills, near Edinburgh, shows that igneous rocks were there formed during the Devonian or ‘Old Red’ period. These hills are 1,900 feet high above the sea, and consist of conglomerates and sandstones of Devonian age, resting on the inclined edges of grits and slates of Upper Silurian date. The contemporaneous volcanic rocks intercalated in this Old Red Sandstone consist of felspathic lavas, or felstones, with associated conglomerates and tuffs or ashy beds. The lavas were some of them originally compact, others vesicular, and these last have been converted into amygdaloids. Unlike the lavas of the Tertiary Period in Scotland they appear to have been of subaqueous rather than of subaërial origin. The evidences of the volcanic origin of the rocks of the Pentland Hills have been well illustrated by Messrs. Maclaren and Geikie.[1]

Silurian volcanic rocks.—It appears from the investigations of Sir R. Murchison in Shropshire, that when the Lower Silurian strata of that country were accumulating, there were frequent volcanic eruptions beneath the sea; and the ashes and scoriæ then ejected gave rise to a peculiar kind of tufaceous sandstone or grit, dissimilar to the other rocks of the Silurian series, and only observable in places where syenitic and other trap rocks protrude. These tuffs occur on the flanks of the Wrekin and Caer Caradoc, and contain Silurian fossils, such as casts of encrinites, trilobites, and mollusca. Although fossiliferous, the stone resembles a sandy claystone of the trap family.[2]

Thin layers of trap, only a few inches thick, alternate in some parts of Shropshire and Montgomeryshire with sedimentary strata of the Lower Silurian system. This trap consists of consolidated felspathic ash with fragments of slate, the beds being traversed by joints like those in the associated sandstone, limestone, and shale, and having the same strike and dip.[3]

In Radnorshire there is an example of twelve bands of stratified trap, alternating with Silurian schists and flagstones, in a thickness of 350 feet. The bedded traps consist of porphyritic felstone, and other varieties; and the interposed Llandeilo flags are of sandstone and shale, with tribolites and graptolites.[4]

The Snowdonian hills in Caernarvonshire consist in great part of volcanic tuffs, the oldest of which are interstratified with the Bala and Llandeilo beds. There are some contemporaneous felspathic lavas of this era, which, says Professor Ramsay, alter the slates on which they repose, having doubtless being poured out over them, in a melted state, whereas the slates which overlie them having been subsequently deposited after the lava had cooled and consolidated, have entirely escaped alteration. But there are greenstones associated with the same formation, which, although they are often conformable to the slates, are in reality intrusive rocks. They alter the stratified deposits both above and below them, and when traced to great distances, are sometimes seen to cut through these slates, and to send off branches. Nevertheless, these greenstones appear to belong, like the lavas, to the Lower Silurian period. In like manner felstones occur contemporaneous with Lower Silurian strata in the Lake District, the Isle of Man, and the S.E. of Ireland.

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[1] Maclaren, Geology of Fife and Lothians. Geikie, Trans. Royal Soc. Edinburgh, 1860–1861.

[2] Murchison, Silurian System, &c., p. 230.

[3] Ibid. p. 212.

[4] Ibid. p. 325.

Cambrian volcanic rocks.—The Lingula beds in North Wales have been described as 5,000 feet in thickness. In the upper portion of these deposits, volcanic tuffs or ashy materials are interstratified with ordinary muddy sediment, and here and there associated with thick beds of felspathic lava. These rocks form the mountains called the Arans and the Arenigs; numerous greenstones are associated with them, which are intrusive, although they often run in the lines of bedding for a space. 'Much of the ash,' says Professor Ramsay, 'seems to have been sub-aërial. Islands, like Graham's Island, may have sometimes raised their craters for various periods above the water, and by the waste of such islands some of the ashy matter became waterworn, whence the ashy conglomerate. Viscous matter seems also to have been shot into the air as volcanic bombs, which fell among the dust and broken crystals (that often form the ashes) before perfect cooling and consolidation had taken place.'[1]

Laurentian volcanic rocks.—The Laurentian rocks in Canada, especially in Ottawa and Argenteuil, are the oldest intrusive masses yet known. They form a set of dikes of a fine-grained dolerite, composed of felspar and pyroxene, with occasional scales of mica and grains of pyrites. Their width varies from a few feet to a hundred yards, and they have a columnar structure, the columns being truly at right angles to the plane with the dike. Some of the dikes send off branches. These dolerites are cut through by intrusive syenite, and this syenite, in its turn, is again cut and penetrated by porphyritic felsite. All these trap rocks appear to be of Laurentian date, as the Cambrian and Huronian rocks rest unconformably upon them.[2] Whether some of the various conformable crystalline rocks of the Laurentian series, such as the coarse-grained granitoid and porphyritic varieties of gneiss, exhibiting scarcely any signs of stratification, and some of the serpentines, may not also be of volcanic origin, is a point very difficult to determine in a region which has undergone so much metamorphic action.

[1] Geol. Quart. Journ,. vol. ix. p. 170, 1852.

[2] Logan, Geology of Canada, 1863.

CHAPTER XXXI.

PLUTONIC ROCKS.

General aspect of plutonic rocks—Granite and its varieties—Decomposing into spherical masses—Rude columnar structure—Graphic granite—Mutual penetration of crystals of quartz and felspar—Glass cavities in quartz of granite—Porphyritic, talcose, and hornblendic granite—Eurite—Syenite—Diorite—Connection of the plutonic with the volcanic rocks—Analogy in composition of trachyte and granite—Granite veins in Glen Tilt, Cape of Good Hope, and Cornwall—Metalliferous veins in strata near their junction with granite—Quartz veins—Exposure of plutonic rocks at the surface due to denudation.

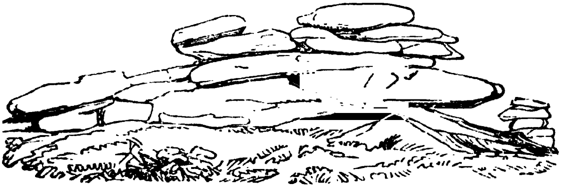
THE plutonic rocks may be treated of next in order, as they are most nearly allied to the volcanic class already considered. I have described, in the first chapter, these plutonic rocks as the unstratified division of the crystalline or hypogene formations, and have stated that they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, whether thrown up into the air or the sea. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases gives rise in ordinary lava, never being scoriaceous or amygdaloidal, nor alternating with tuffs.

From these and other peculiarities it has been inferred that the granites have been formed at considerable depths in the earth, and have cooled and crystallised slowly under great pressure, where the contained gases could not expand. The volcanic rocks, on the contrary, although they also have risen up from below, have cooled from a melted state more rapidly upon or near the surface. From this hypothesis of the great depth at which the granites originated, has been derived the name of 'Plutonic rocks.' The beginner will easily conceive that the influence of subterranean heat may extend downwards from the crater of every active volcano to a great depth below, perhaps several miles or leagues, and the effects which are produced deep in the bowels of the earth may, or rather must, be distinct; so that volcanic and plutonic rocks, each different in texture, and sometimes even in composition, may originate simulta-

The two principal members of the Plutonic family of rocks are Granite and Syenite, each of which, with their varieties, bear very much the same relation to each other as the trachytes bear to the basalts. Granite is a compound of felspar, quartz, and mica, the felspars being rich in silica, which forms from 60 to 70 per cent. of the whole aggregate. In syenite quartz is rare or wanting, hornblende taking the place of mica, and the proportion of silica seldom exceeding 60 per cent.

Granite and its varieties.—Granite often preserves a very uniform character throughout a wide range of territory, frequently forming hills of a peculiar rounded form, clad with a scanty vegetation. The surface of the rock is for the most part in a crumbling state, and the hills are often surmounted by piles of stones like the remains of a stratified mass, as in the annexed figure, and sometimes like heaps of boulders, for which they have been mistaken. The exterior of these stones, originally quadrangular, acquires a rounded form by the action of air and water, for the edges and angles waste away more rapidly than the sides. A similar spherical structure has already been described as characteristic of basalt and other volcanic formations, and it must be referred to analogous causes, as yet but imperfectly understood. Although it is the general peculiarity of granite to assume no definite shapes, it is nevertheless occasionally subdivided by fissures, so as to assume a cuboidal, and even a columnar, structure. Examples of these appearances may be seen near the Land's End in Cornwall. (See fig. 615.)

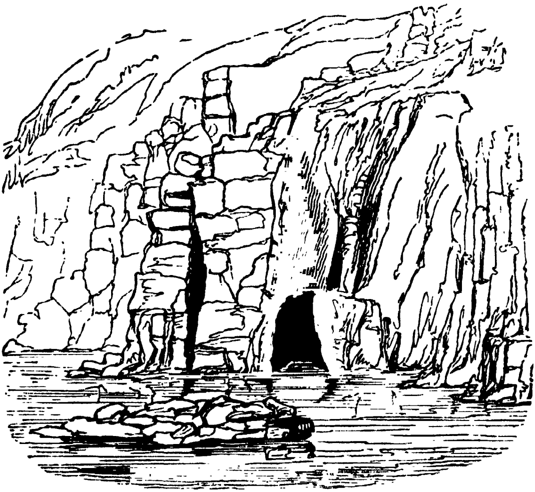
Fig. 614.



Mass of granite near the Sharp Tor, Cornwall.

Felspar, quartz, and mica are considered as the minerals essential to granite, the felspar being most abundant in quantity, and the proportion of quartz exceeding that of mica. These minerals are united in what is termed a confused crystallisation; that is to say, there is no regular arrangement of the crystals in granite, as in gneiss (see fig. 631, p. 577), except in the variety termed graphic granite, which occurs mostly in granitic veins. This variety is a compound of felspar and

Fig. 615.



Granite having a cuboidal and rude columnar structure, Land's End, Cornwall.

Fig. 616.

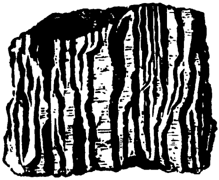
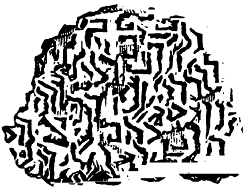


Fig. 617.



Graphic granite.

Fig. 616. Section parallel to the laminæ.
Fig. 617. Section transverse to the laminæ.

quartz, so arranged as to produce an imperfect laminar structure. The crystals of felspar appear to have been first formed, leaving between them the space now occupied by the darker-coloured quartz. This mineral, when a section is made at right angles to the alternate plates of felspar and quartz, presents broken lines, which have been compared to Hebrew characters. (See fig. 617.) The variety of granite called by the French *Pegmatite*, which is a mixture of quartz and common felspar, usually with some small admixture of white silvery mica, often passes into graphic granite.

Ordinary granite usually contains two different felspars, which in most cases are the species known under the name of orthoclase and oligoclase. As a general rule quartz serves as a base in which the felspar and mica have crystallised; for although these minerals are much more fusible than silex, they have often imprinted their shapes upon the quartz. This fact, apparently so paradoxical, has given rise to much ingenious speculation. We should naturally have anticipated that, during the cooling of the mass, the siliceous portion would be the first to consolidate; and that the different varieties of felspar, as well as garnets and tourmalines, being more easily liquefied by heat, would be the last. Precisely the reverse has taken place in the passage of most granite aggregates from a fluid to a solid state, crystals of the more fusible minerals being found enveloped in hard, transparent, glassy quartz, which has often taken very faithful casts of each, so as to preserve even the microscopically minute striations on the surface of prisms of tourmaline. Various explanations of this phenomenon have been proposed by MM. de Beaumont, Fournet, and Durocher. They refer to M. Gaudin's experiments on the fusion of quartz, which show that silex, as it cools, has the property of remaining in a viscous state, whereas silicate of alumina never does. This 'gelatinous flint is supposed to retain a considerable degree of plasticity long after the granitic mixture has acquired a low temperature. Occasionally we find the quartz and felspar mutually imprinting their forms on each other, affording evidence of the simultaneous crystallisation of both.'[1]

According to the experiments and observations of Gustavus Rose, the quartz of granite has the specific gravity of 2·6, which characterises silica when it is precipitated from a liquid solvent, and not that inferior density, namely 2·3, which belongs to it when it cools in the laboratory, from a state of fusion in what is called the dry way. By some it had been rashly inferred that the manner in which the consolidation of granite takes place is exceedingly different from the cooling of lavas, and that the intense heat supposed to be necessary for the production of mountain masses of plutonic rocks might be dispensed with. But Mr. David Forbes informs me that silica can crystallise in the dry way, and he has found in quartz forming a constituent part of some trachytes, both from Guadaloupe and Iceland, glass cavities quite similar to those met with in genuine volcanic minerals.

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[1] Bulletin, 2e série, iv. 1304; and D'Archiac, Hist. des Progrès de la Géol., i. 38.

These 'glass cavities,' which with many other kindred phenomena have been carefully studied by Mr. Sorby, are those in which a liquid, on cooling, has become first viscous and then solid without crystallising or undergoing a definite change in its physical structure. Other cavities which, like those just mentioned, are frequently discernible under the microscope in the minerals composing granitic rocks, are filled some of them with gas or vapour, others with liquid, and by the movements of the bubbles thus included the distinctness of such cavities from those filled with a glassy substance can be tested. Mr. Sorby admits that the frequent occurrence of fluid cavities in the quartz of granite implies that water was almost always present in the formation of this rock; but the same may be said of almost all lavas, and it is now more than forty years since Mr. Scrope insisted on the important part which water plays in volcanic eruptions, being so intimately mixed up with the materials of the lava that he supposed it to aid in giving mobility to the fluid mass. It is well known that steam escapes for months, sometimes for years, from the cavities of lava when it is cooling and consolidating. As to the result of Mr. Sorby's experiments and speculations on this difficult subject, they may be stated in a few words. He concludes that the physical conditions under which the volcanic and granitic rocks originate are so far similar that in both cases they combine igneous fusion, aqueous solution, and gaseous sublimation—the proof, he says, of the operation of water in the formation of granite being quite as strong as of that of heat.[1]

When rocks are melted at great depths water must be present, for two reasons—First, because rain-water and sea-water are always descending through fissured and porous rocks, and must at length find their way into the regions of subterranean heat; and secondly, because in a state of combination water enters largely into the composition of some of the most common minerals, especially those of the aluminous class. But the existence of water under great pressure affords no argument against our attributing an excessively high temperature to the mass with which it is mixed up. Bunsen, indeed, imagines that in Iceland water attains a white heat at a very moderate depth. To what extent some of the metamorphic rocks containing the same minerals as the granites may have been formed by hydrothermal action without the intervention of intense heat comparable to that brought into play in a volcanic eruption, will be considered when we treat of the metamorphic rocks in the thirty-third chapter.

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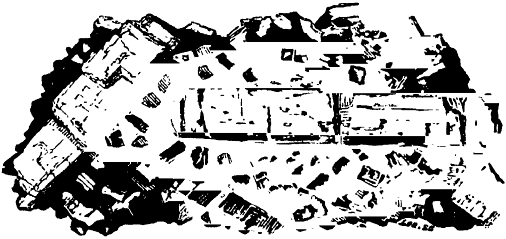
[1] See Quart. Geol. Journ., vol. xiv. pp. 465, 488.

Porphyritic granite.—This name has been sometimes given to that variety in which large crystals of felspar, usually orthoclase, sometimes more than 3 inches in length, are scattered through an ordinary base of granite. An example of this texture may be seen in the granite of the Land's End, in Cornwall (fig. 618).

Fig. 618.



Porphyritic granite. Land's End, Cornwall.

The two larger prismatic crystals in this drawing represent orthoclase felspar, smaller crystals of which are also seen, similar in form, scattered through the base. In this base also appear black specks of mica, the crystals of which have a more or less perfect hexagonal outline. The remainder of the mass is quartz, the translucency of which is strongly contrasted to the opacity of the white felspar and black mica. But neither the transparency of the quartz nor the silvery lustre of the mica can be expressed in the engraving.

The uniform mineral character of large masses of granite seems to indicate that large quantities of the component elements were thoroughly mixed up together, and then united into crystallised minerals under precisely similar conditions. There are, however, many accidental, or 'accessory' minerals, as they are termed, which occur in granite. Among these black schorl or tourmaline, actinolite, zircon, garnet, iron-pyrites, sphene, apatite, and fluor-spar are not uncommon; but they are as a general rule too sparingly dispersed to modify the general aspect of the rock. They show, nevertheless, that the ingredients were not everywhere exactly the same; and a still greater difference may be traced in the ever-varying proportions of the felspar, quartz, and mica.

Talcose granite, or Protogine of French authors, a rock very abundant in the Alps, is a granite, or sometimes only a highly metamorphic form of gneiss, which contains in addition to the ordinary minerals varying quantities of a substance formerly supposed to be talc, but which may be altered mica.

Felsite, or *Eurite*, is a rock which in chemical composition differs little from many trachytes and granites. The matrix of the rock has a compact appearance, consisting of an intimate mixture of felspar and quartz imperfectly crystallised, and is commonly of a light colour. It is often porphyritic, containing crystals of felspar (usually orthoclase) and quartz, the latter mineral being very variable in quantity. Felsites containing much quartz are often called *Quartz-porphyry*, and when only felspar crystals are present *Orthoclase-porphyry*, the name felsite being reserved for the non-porphyritic varieties. A rock in which oligoclase appears to replace orthoclase felspar, and from which quartz is absent, is generally termed *porphyrite*, though the name is objectionable. It is abundant in the Pentland and Ochil Hills in Scotland. All these species are comprehended in the one term *Felstone*. They appear to occupy an intermediate position between the trachytes and the truly crystalline granites, a circumstance which affords one of many arguments in favour of what is now the prevailing opinion, that the granites are also of igneous origin.

Hornblendic granite.—The quadruple compound of quartz, felspar, mica, and hornblende may be so termed, and form a passage between granite and quartziferous syenite. This rock occurs at Mount Sorrel in Leicestershire, and in Scotland and Guernsey.

Syenite.—Syenite is the name given to rocks composed of orthoclase felspar and hornblende with occasionally some quartz and mica; it usually contains more than 55 but rarely above 60 per cent. of silica. Although its name is derived from the celebrated quarries of Syene in Egypt, more recent researches have shown that the rock there is in reality a hornblendic granite. *Miascite*, so called from Miask in the Ural Mountains, and *Zircon syenite*, are both varieties of syenite which contain nepheline; the latter being further characterised by the presence of crystals of zircon.

Diorite is a rock made up of triclinic felspar, usually oligoclase, with hornblende and occasionally a little quartz; it contains still less silica than syenite.

Diabase.—This term is given to a mixture of triclinic felspar, augite and a little chlorite, containing about 50 per cent. of silica. This rock is extremely abundant in North Wales, where in the vicinity of Dolgelly, amongst other varieties, the so-called uralite porphyry is met with, in which the augite is in part replaced by uralite, a mineral already alluded to (pp. 498, 502).

Gabbro or Euphotide is also a rock composed of triclinic felspar and diallage, in which olivine is frequently present. It is also called diallage rock, and is well exhibited near the Lizard Promontory in Cornwall. One variety contains smaragdite, which is usually regarded as a variety of hornblende. This rock is closely allied both to hyperite or hypersthene rock.

Connection of the plutonic with the volcanic rocks.—The minerals which constitute alike the plutonic and volcanic rocks consist, almost exclusively, of seven constituents, namely, silica, alumina, magnesia, lime, soda, potash, and oxide of iron (Table, p. 498). In making chemical analyses of specimens obtained in the field the student may often be perplexed by finding that these constituents appear to exist in equal proportions in very different classes of rocks. But Mr. David Forbes has pointed out in an admirable pamphlet on Chemical Geology that this arises from the inexperience of the geologist in choosing the typical portion to be examined; for example, when diorite (composed of felspar and hornblende) is erupted through quartzose strata it will usually absorb more or less of quartz particles, thus becoming apparently a syenite (a mixture of felspar, hornblende and quartz); yet the mass of the erupted rock, except at points of contact, is unquestionably a diorite, and a microscopic examination of the quartziferous portion will show that the quartz had become entangled in the erupted mass, and was not an original constituent of it. It may thus often happen that small specimens roughly named by the geologist porphyry, granite, syenite, mica-schist and gneiss, might be pronounced by the chemist identical in chemical composition, whereas the truth would be that all these specimens were in reality miscalled, being merely abnormal varieties altered in appearance and composition by exceptional influences.[1]

'The ordinary granite of Aberdeenshire,' says Dr. MacCulloch, 'is the usual ternary compound of quartz, felspar, and mica; though sometimes hornblende is substituted for the mica. But in many places a variety occurs which is composed simply of felspar and hornblende; and in examining more minutely this duplicate compound, it is observed in some places to assume a fine grain, and at length to become undistinguishable from the greenstones of the trap family. It also passes in the same uninterrupted manner into a basalt, and at length into a soft claystone, with a schistose tendency on exposure, in no respect differing from those of the trap islands of the western coast.'[1] In Hungary there are varieties of trachyte, which, geologically speaking, are of modern origin, in which crystals, not only of mica, but of quartz, are common, together with felspar and hornblende. It is easy to conceive how such volcanic masses may, at a certain depth from the surface, pass downwards into granite.

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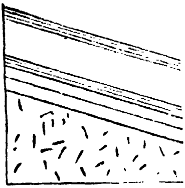
[1] Forbes, Study of Chemical Geology, 1866.

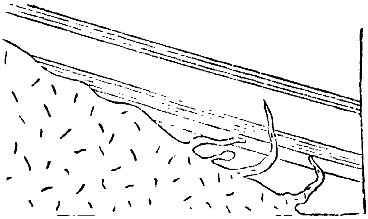
Granitic veins.—I have already hinted at the close analogy in the forms of certain granitic and trappean veins; and it will be found that strata penetrated by plutonic rocks have suffered changes very similar to those exhibited near the contact of volcanic dikes. Thus, in Glen Tilt, in Scotland, alternating strata of limestone and argillaceous schist come in contact with a mass of granite. The contact does not take place as might have been looked for, if the granite had been formed there before the strata were deposited, in which case the section would have appeared as in fig. 619; but the union is as represented in fig. 620, the undulating outline of the granite intersecting different strata, and occasionally intruding itself in tortuous veins into the beds of clay-slate and limestone, from which it differs so remarkably in composition. The limestone is sometimes changed in character by the proximity of the granitic mass or its veins, and acquires a more compact texture, like that of hornstone or

Fig. 619.



Section as it would appear if the strata had been deposited on the granite.

Fig. 620.



Junction of granite and argillaceous schist in Glen Tilt. (MacCulloch.)[2]

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[1] Syst. of Geol., vol. i. pp. 157 and 158.
[2] Geol. Trans., First Series, vol. iii. pl. 21.

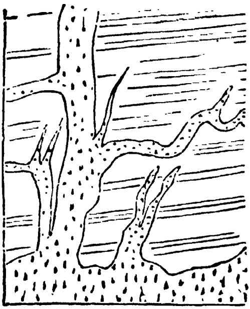
chert, with a splintery fracture, and effervescing slowly with acids.

The conversion of the limestone in these and many other instances into a siliceous rock, effervescing slowly with acids, would be difficult of explanation, were it not ascertained that such limestones are always impure, containing grains of quartz, mica, or felspar disseminated through them. The elements of these minerals, when the rock has been subjected to great heat, may have been fused, and so spread more uniformly through the whole mass.

In the plutonic, as in the volcanic rocks, there is every gradation from a tortuous vein to the most regular form of a dike, such as intersect the tuffs and lavas of Vesuvius and Etna. Dikes of granite may be seen, among other places, on the southern flank of Mount Battock, one of the Grampians, the opposite walls sometimes preserving an exact parallelism for a considerable distance. As a general rule, however, granite veins in all quarters of the globe are more sinuous in their course than those of trap. They present similar shapes at the most northern point of Scotland, and the southernmost extremity of Africa, as the annexed drawings will show.

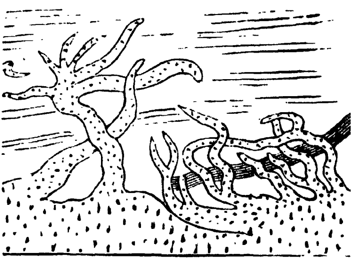
It is not uncommon for one set of granite veins to intersect another; and sometimes there are three sets, as in the environs Heidelberg, where the granite on the banks of the river Neckar is seen to consist of three varieties, differing in colour, grain and various peculiarities of mineral composition. One

Fig. 621.



Granite veins traversing clay slate, Table Mountain, Cape of Good Hope.[1]

Fig. 622.



Granite veins traversing gneiss, Cape Wrath. (MacCulloch.)[2]

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[1] Capt. B. Hall, Trans. Roy. Soc. Edinburgh, vol. vii.

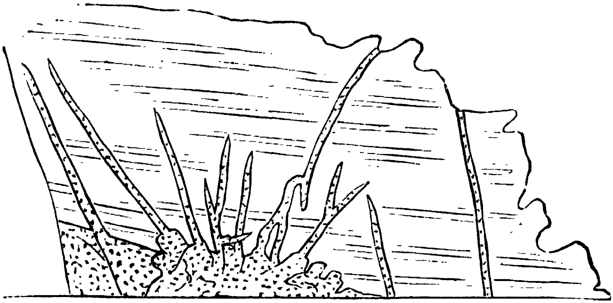
[2] Western Islands, pl. 31.

of these, which is evidently the second in age, is seen to cut through an older granite ; and another, still newer, traverses both the second and the first. In Shetland there are two kinds of granite. One of them, composed of hornblende, mica, felspar, and quartz, is of a dark colour, and is seen underlying gneiss. The other is a red granite, which penetrates the dark variety everywhere in veins.[1]

Fig. 623 is a sketch of a group of granite veins in Cornwall, given by Messrs. Von Oeynhausen and Von Dechen.[2] The main body of the granite here is of a porphyritic appearance, with large crystals of felspar ; but in the veins it is fine-grained, and without these large crystals. The general height of the veins is from 16 to 20 feet, but some are much higher.

The granites, syenites, diorites, granitic felsites, and indeed all plutonic rocks, are frequently observed to contain metallic veins at or near their junction with stratified formations. On the other hand, similar veins which traverse stratified rocks are, as a general law, more metalliferous near such junctions than in other positions. Hence it has been inferred that these metals may have been spread in a gaseous form through the fused mass, and that the contact of another rock, in a different state of temperature, or sometimes the existence of rents in other rocks in the vicinity, may have caused the sublimation of the metals.[3]

Fig. 623.



Granite veins passing through hornblende slate, Carnsilver Cove, Cornwall.

Veins of pure quartz are often found in granite as in many stratified rocks, but they are not traceable, like veins of granite or trap, to large bodies of rock of similar composition. They appear to have been cracks, into which siliceous matter was infiltrated. Such segregation, as it is called, can sometimes clearly be shown to have taken place long subsequently to the original consolidation of the containing rock. Thus for example, I observed in the gneiss of Tronstad Strand, near Drammen, in Norway, the annexed section on the beach. It appears that the alternating strata of whitish graniteform gneiss and black hornblende schist were first cut through by a greenstone dike, about 2½ feet wide; then the crack *a*, *b*, passed through all these rocks, and was filled up with quartz. The opposite walls of the veins are in some parts incrusted with transparent crystals of quartz, the middle of the vein being filled up with common opaque white quartz.

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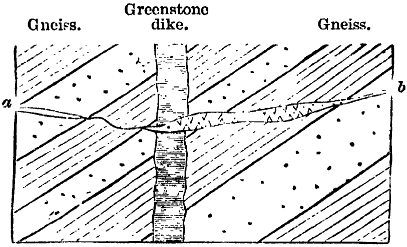
[1] MacCulloch, Syst. of Geol., vol. i. p. 58.

[2] Phil. Mag. and Annals, No. 27, New Series, March 1829.

[3] Necker, Proceedings of Geol. Soc. No. 26, p. 392.

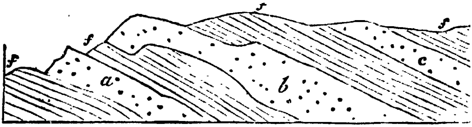
We have seen that the volcanic formations have been called overlying, because they not only penetrate others but spread over them. M. Necker has proposed to call the granites the underlying igneous rocks, and the distinction here indicated is highly characteristic. It was indeed supposed by some of the earlier observers, that the granite of Christiania, in Norway, was intercalated in mountain masses between the primary or palæozoic strata of that country, so as to overlie fossiliferous shale and limestone. But although the granite sends veins into these fossiliferous rocks, and is decidedly posterior in origin, its actual superposition in mass has been disproved by Professor

Fig. 624.



a, *b*. Quartz vein passing through gneiss and greenstone, Tronstadt Strand, near Christiania.

Fig. 625.



Porphyritic eurite alternating with primary fossiliferous strata, near Christiania.

Keilhau, whose observations on this controverted point I had opportunities in 1837 of verifying. There are, however, on a smaller scale, certain beds of porphyritic eurite, some a few feet, others many yards in thickness, which pass into granite, and deserve perhaps to be classed as plutonic rather than trappean rocks, which may truly be described as interposed conformably between fossiliferous strata, as the eurites (*a*, *c*, fig. 625), which divide the bituminous shales and argillaceous limestones, *f f*. But some of these same eurites are partially unconformable, as *b*, and may lead us to suspect that the others also, notwithstanding their appearance of interstratification, have been forcibly injected. Some of the porphyritic rocks above mentioned are highly quartzose, others very felspathic. In proportion as the masses are more voluminous, they become more granitic in their texture, less conformable, and even begin to send forth veins into contiguous strata. In a word, we have here a beautiful illustration of the intermediate gradations between volcanic and plutonic rocks, not only in their mineralogical composition and structure, but also in their relations of position to associated formations. If the term 'overlying' can in this instance be applied to a plutonic rock, it is only in proportion as that rock begins to acquire a trappean aspect.

It has been already hinted that the heat, which in every active volcano extends downwards to indefinite depths, must produce simultaneously very different effects near the surface and far below it; and we cannot suppose that rocks resulting from the crystallising of fused matter under a pressure of several thousand feet, much less several miles, of the earth's crust can exactly resemble those formed at or near the surface. Hence the production at great depths of a class of rocks analogous to the volcanic, and yet differing in many particulars, might have been predicted, even had we no plutonic formations to account for. How well these agree, both in their positive and negative characters, with the theory of their deep subterranean origin, the student will be able to judge by considering the descriptions already given.

It has, however, been objected, that if the granitic and volcanic rocks were simply different parts of one great series, we ought to find in mountain chains volcanic dikes passing upwards into lava and downwards into granite. But we may answer that our vertical sections are usually of small extent; and if we find in certain places a transition from trap to porous lava, and in others a passage from granite to trap, it is as much as could be expected of this evidence.

The prodigious extent of denudation which has been already demonstrated to have occurred at former periods, will reconcile the student to the belief that crystalline rocks of high antiquity, although deep in the earth's crust when originally formed, may have become uncovered and exposed at the surface. Their actual elevation above the sea may be referred to the same causes to which we have attributed the upheaval of marine strata, even to the summits of some mountain chains.

CHAPTER XXXII.

ON THE DIFFERENT AGES OF THE PLUTONIC ROCKS.

Difficulty in ascertaining the precise age of a plutonic rock—Test of age by relative position—Test by intrusion and alteration—Test by mineral composition—Test by included fragments—Recent and Pliocene plutonic rocks, why invisible—Miocene syenite of the Isle of Skye—Eocene plutonic rocks in the Andes—Granite altering Cretaceous rocks—Granite altering Lias in the Alps—Granite of Dartmoor altering Carboniferous strata—Granite of the Old Red Sandstone Period—Syenite altering Silurian strata in Norway—Blending of the same with gneiss—Most ancient plutonic rocks—Granite protruded in a solid form.

When we adopt the igneous theory of granite, as explained in the last chapter, and believe that different plutonic rocks have originated at successive periods beneath the surface of the planet, we must be prepared to encounter greater difficulty in ascertaining the precise age of such rocks, than in the case of volcanic and fossiliferous formations. We must bear in mind, that the evidence of the age of each contemporaneous volcanic rock was derived, either from lavas poured out upon the ancient surface, whether in the sea or in the atmosphere, or from tuffs and conglomerates, also deposited at the surface, and either containing organic remains themselves, or intercalated between strata containing fossils. But the same tests entirely fail or are only applicable in a modified degree when we endeavour to fix the chronology of a rock which has crystallised from a state of fusion in the bowels of the earth. In that case, we are reduced to the tests of relative position, intrusion, alteration of the rocks in contact, included fragments, and mineral character; but all these may yield at best a somewhat ambiguous result.

Test of age by relative position.—Unaltered fossiliferous strata of every age are met with reposing immediately on plutonic rocks; as at Christiania, in Norway, where the Pleistocene deposits, and at Heidelberg, on the Neckar, and Mount Sorrel in Leicestershire, where the New Red Sandstone formations rest on granite. In these, and similar instances, inferiority in position is connected with the superior antiquity of granite. The crystalline rock was solid before the sedimentary beds were superimposed, and the latter usually contain in them rounded pebbles of the subjacent granite.

Test by intrusion and alteration.—But when plutonic rocks send veins into strata, and alter them near the point of contact, in the manner before described (p. 559), it is clear that, like intrusive traps, they are newer than the strata which they invade and alter. Examples of the application of this test will be given in the sequel.

Test by mineral composition.—Notwithstanding a general uniformity in the aspect of plutonic rocks, we have seen in the last chapter that there are many varieties, such as hornblendic granite, talcose granite, and others. One of these varieties is sometimes found exclusively prevailing throughout an extensive region, where it preserves a homogeneous character; so that, having ascertained its relative age in one place, we can recognise its identity in others, and thus determine from a single section the chronological relations of large mountain masses. Having observed, for example, that the syenite of Norway, in which the mineral called zircon abounds, has altered the Silurian strata wherever it is in contact, we do not hesitate to refer other masses of the same zircon-syenite in the south of Norway to a post-Silurian date. Some have imagined that the age of different granites might, to a great extent, be determined by their mineral characters alone; granite with hornblende, for instance, being more modern than common or micaceous granite. But modern investigations have proved these generalisations to have been premature.

Test by included fragments.—This criterion can rarely be of much importance, because the fragments involved in granite are usually so much altered, that they cannot be referred with certainty to the rocks whence they were derived. In the White Mountains, in North America, according to Professor Hubbard, a granite vein, traversing granite, contains fragments of slate and trap which must have fallen into the fissure when the fused materials of the vein were injected from below,[1] and thus the granite is shown to be newer than those slaty and trappean formations from which the fragments were derived.

Recent and Pliocene plutonic rocks, why invisible.—The explanations already given in the 28th and in the last chapter of the probable relation of the plutonic to the volcanic formations, will naturally lead the reader to infer that rocks of the one class can never be produced at or near the surface without some members of the other being formed below. It is not uncommon for lava-streams to require more than ten years to cool in the open air ; and where they are of great depth, a much longer period. The melted matter poured from Jorullo, in Mexico, in the year 1759, which accumulated in some places to the height of 550 feet, was found to retain a high temperature half a century after the eruption.[1] We may conceive, therefore, that great masses of subterranean lava may remain in a red-hot or incandescent state in the volcanic foci for immense periods, and the process of refrigeration may be extremely gradual. Sometimes, indeed, this process may be retarded for an indefinite period, by the accession of fresh supplies of heat ; for we find that the lava in the crater of Stromboli, one of the Lipari Islands, has been in a state of constant ebullition for the last two thousand years ; and we may suppose this fluid mass to communicate with some caldron or reservoir of fused matter below. In the Isle of Bourbon, also, where there has been an emission of lava once in every two years for a long period, the lava below can scarcely fail to have been permanently in a state of liquefaction. If then it be a reasonable conjecture, that about 2,000 volcanic eruptions occur in the course of every century, either above the waters of the sea or beneath them,[2] it will follow that the quantity of plutonic rock generated, or in progress during the Recent epoch, must already have been considerable.

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[1] Silliman's Journ., No. 69, p. 123.

But as the plutonic rocks originate at some depth in the earth's crust, they can only be rendered accessible to human observation by subsequent upheaval and denudation. Between the period when a plutonic rock crystallises in the subterranean regions and the era of its protrusion at any single point of the surface, one or two geological periods must usually intervene. Hence, we must not expect to find the Recent or even the Pliocene granites laid open to view, unless we are prepared to assume that sufficient time has elapsed since the commencement of the Pliocene period for great upheaval and denudation. A plutonic rock, therefore, must, in general, be of considerable antiquity relatively to the fossiliferous and volcanic formations, before it becomes extensively visible. As we know that the upheaval of land has been sometimes accompanied in South America by volcanic eruptions and the emission of lava, we may conceive the more ancient plutonic rocks to be forced upwards to the surface by the newer rocks of the same class formed successively below,—subterposition in the plutonic, like superposition in the sedimentary rocks, being usually characteristic of a newer origin.

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[1] See 'Principles,' *Index*, 'Jorullo.'

[2] Ibid., 'Volcanic Eruptions.'

In the accompanying diagram (fig. 626), an attempt is made to show the inverted order in which sedimentary and plutonic formations may occur in the earth's crust. The oldest plutonic rock, No. I., has been upheaved at successive periods until it

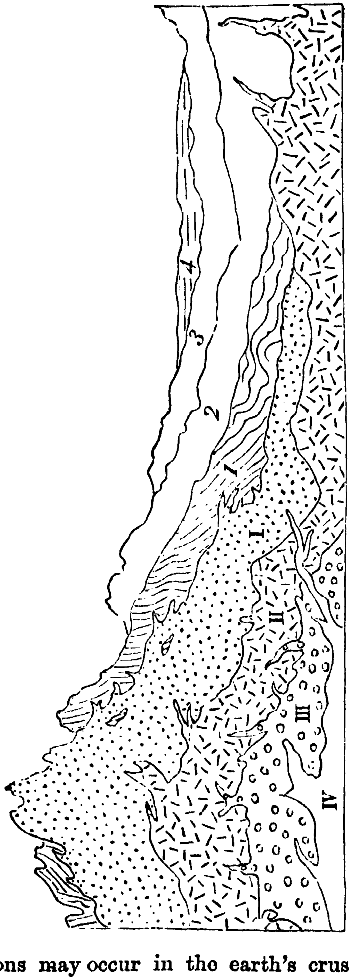

Fig. 626.

Diagram showing the relative position which the plutonic and sedimentary formations of different ages may occupy.

I. Primary plutonic rocks.
II. Secondary plutonic rocks.
III. Tertiary plutonic rocks.
IV. Post-tertiary plutonic rocks.

1. Primary fossiliferous or Palæozoic strata.
2. Secondary or Mesozoic strata.
3. Tertiary or Cainozoic strata.
4. Post-tertiary strata.

The metamorphic rocks are not indicated in this diagram; but the student will infer, from what is said in Chaps. XXXI. and XXXIII., that some portions of the stratified formations, Nos. 1 and 2, invaded by granite, will have become metamorphic.

has become exposed to view in a mountain-chain. This protrusion of No. I. has been caused by the igneous agency which produced the newer plutonic rocks Nos. II. III. and IV. Part of the primary fossiliferous strata, No. I., have also been raised to the surface by the same gradual process. It will be observed that the Recent *strata* No. 4 and the Recent *granite* or plutonic rock No. IV. are the most remote from each other in position, although of contemporaneous date. According to this hypothesis, the convulsions of many periods will be required before Recent or Post-tertiary granite will be upraised so as to form the highest ridges and central axes of mountain-chains. During that time the *Recent* strata No. 4 might be covered by a great many newer sedimentary formations.

Tertiary plutonic rocks.—At many different points in the Hebrides, as in Skye, Mull, Rum, St. Kilda, &c., great masses of granite and syenite are found in close association with the Tertiary volcanic rocks which have been before described.[1] Dr. MacCulloch described the syenites of Skye as intersecting limestone and shale which are of the age of the lias. The limestone, which at a greater distance from the granite contains shells, exhibits no traces of them near its junction, where it has been converted into a highly crystalline marble.

MacCulloch pointed out that the granite and syenite here, as in Raasay, was newer than the secondary strata of these islands, and Prof. A. Geikie afterwards showed that in Mull there are strong grounds for believing these granites and syenites to be of Tertiary age, like the volcanic rocks, with which they are so intimately associated. Professor Zirkel, of Leipsic, has discovered that both in Mull and Skye there are great mountain masses of intrusive rocks, consisting of gabbro containing much olivine, which have been erupted subsequently to the granites. In Skye these gabbros constitute the remarkable Cuchullin Hills, which are so famed for their wild and majestic scenery. And lastly Mr. Judd has shown that the great mountain groups in the Hebrides, composed of granites and gabbros, constitute the relics of five grand volcanoes which were in eruption during a great part of the Tertiary period, the earlier formed masses of granite being connected with the series of felspathic lavas probably of Eocene age; while the gabbros, which break through the granites, are the consolidated reservoirs that gave rise to the great streams of basaltic lava of Miocene age, which constitute the plateaux forming so large a portion of the Hebridean Archipelago. These researches show that the western isles of Scotland afford a most admirable and instructive series of illustrations of the intimate connection between the rocks of the volcanic and the plutonic classes respectively; and at the same time of the perfect identity in their nature and sequence, of the phenomena of volcanic activity during former periods of the earth's history, and those which are exhibited to us at the present day. There are strong grounds for believing that the granites of Arran and the Mourne Mountains in Ireland are of the same age as those of Skye, Mull, Rum, &c.[1]

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[1] Judd, 'Ancient Volcanoes of the Highlands,' Geol. Soc., Jan 1874.

In a former part of this volume (p. 260), the great nummulitic formation of the Alps and Pyrenees was referred to the Eocene period, and it follows that vast movements which have raised those fossiliferous rocks from the level of the sea to the height of more than 10,000 feet above its level have taken place since the commencement of the Tertiary epoch. Here, therefore, if anywhere, we might expect to find hypogene formations of Eocene date breaking out in the central axis or most disturbed region of the loftiest chain in Europe. Accordingly, in the Swiss Alps, even the *flysch*, or upper portion of the nummulitic series, has been occasionally invaded by plutonic rocks, and converted into crystalline schists of the hypogene class. There can be little doubt that even the talcose granite or gneiss of Mont Blanc itself has been in a fused or pasty state since the *flysch* was deposited at the bottom of the sea; and the question as to its age is not so much whether it be a secondary or tertiary granite or gneiss, as whether it should be assigned to the Eocene or Miocene epoch.

Great upheaving movements have been experienced in the region of the Andes, during the Post-tertiary period. In some part, therefore, of this chain, we may expect to discover tertiary plutonic rocks laid open to view; and Mr. Darwin's account of the Chilian Andes, to which the reader may refer, fully realises this expectation.

But the theory adopted in this work of the subterranean origin of the hypogene formations would be untenable, if the supposed fact here alluded to, of the appearance of tertiary granite at the surface, was not a rare exception to the general rule. A considerable lapse of time must intervene between the formation of plutonic and metamorphic rocks in the nether regions, and their emergence at the surface. For a long series of subterranean movements must occur before such rocks can be uplifted into the atmosphere or the ocean; and, before they can be rendered visible to man, some strata which previously covered them must have been stripped off by denudation.

We know that in the Bay of Baiæ in 1538, in Cutch in 1819, and on several occasions in Peru and Chili, since the commencement of the present century, the permanent upheaval or subsidence of land has been accompanied by the simultaneous emission of lava at one or more points in the same volcanic region. From these and other examples it may be inferred that the rising or sinking of the earth's crust, operations by which sea is converted into land, and land into sea, are a part only of the consequences of subterranean igneous action. It can scarcely be doubted that this action consists, in a great degree, of the baking, and occasionally the liquefaction, of rocks, causing them to assume, in some cases a larger, in others a smaller volume than before the application of heat. It consists also in the generation of gases, and their expansion by heat, and the injection of liquid matter into rents formed in superincumbent rocks. The prodigious scale on which these subterranean causes have operated in Sicily since the deposition of the Newer Pliocene strata will be appreciated, when we remember that throughout half the surface of that island such strata are met with, raised to the height of from 50 to that of 2,000 and even 3,000 feet above the level of the sea. In the same island also the older rocks which are contiguous to these marine tertiary strata must have undergone, within the same period, a similar amount of upheaval.

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[1] Judd, 'Ancient Volcanoes of the Highlands,' Geol. Soc., Jan. 1874.

The like observations may be extended to nearly the whole of Europe, for, since the commencement of the Eocene Period, the entire European area, including some of the central and very lofty portions of the Alps themselves, as I have elsewhere shown,[1] has, with the exception of a few districts, emerged from the deep to its present altitude. There must, therefore, have been at great depths in the earth's crust, within the same period, an amount of subterranean change, corresponding to this vast alteration of level affecting a whole continent.

The principal effect of subterranean movements during the Tertiary Period seems to have consisted in the upheaval of hypogene formations of an age anterior to the Carboniferous. The repetition of another series of movements, of equal violence, might upraise the plutonic and metamorphic rocks of many secondary periods; and, if the same force should still continue to act, the next convulsions might bring up to the day the *tertiary* and *recent* hypogene rocks. In the course of such changes many of the existing sedimentary strata would suffer greatly by denudation, others might assume a metamorphic structure, or become melted down into plutonic and volcanic rocks. Meanwhile the deposition of a great thickness of new strata would not fail to take place during the upheaval and partial destruction of the older rocks. But I must refer the reader to the last chapter but one of this volume for a fuller explanation of these views.

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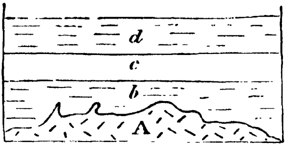
[1] See map of Europe and explanation, in Principles, book i.

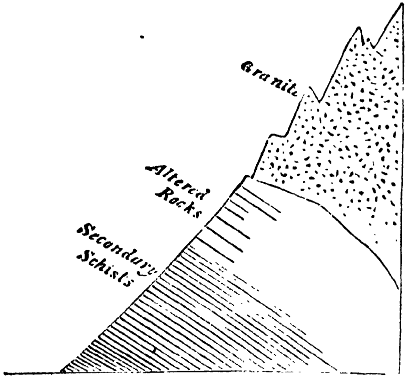
Plutonic rocks of Cretaceous Period.– It will be shown in the next chapter that chalk, as well as lias, has been altered by granite in the eastern Pyrenees. Whether such granite be cretaceous or tertiary cannot easily be decided. Suppose *b*, *c*, *d*, fig. 627, to be three members of the Cretaceous series, the lowest of which, *b*, has been altered by the granite A, the modifying influence not having extended so far as *c*, or having but slightly affected its lowest beds. Now it can rarely be possible for the geologist to decide whether the beds *d* existed at the time of the intrusion of A, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*. But as some Cretaceous and even tertiary rocks have been raised to the height of more than 9,000 feet in the Pyrenees, we must not assume that plutonic formations of the same periods may not have been brought up and exposed by denudation, at the height of 2,000 or 3,000 feet on the flanks of that chain.

Fig. 627.



Plutonic rocks of the Oolite and Lias.—In the Department of the Hautes Alpes, in France, M. Élie de Beaumont traced a black argillaceous limestone, charged with belemnites, to within a few yards of a mass of granite. Here the limestone begins to put on a granular texture, but is extremely fine-grained. When nearer the junction it becomes grey, and has a saccharoid structure. In another locality, near Champoleon, a granite composed of quartz, black mica, and rose-coloured felspar is

Fig. 628.



Junction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

observed partly to overlie the secondary rocks, producing an alteration which extends for about 30 feet downwards, diminishing in the beds which lie farthest from the granite. (See fig. 628.) In the altered mass the argillaceous beds are hardened, the limestone is saccharoid, the grits quartzose, and in the midst of them is a thin layer of an imperfect granite. It is also an important circumstance that near the point of contact, both the granite and the secondary rocks become metalliferous, and contain nests and small veins of blende, galena, iron, and copper pyrites. The stratified rocks become harder and more crystalline, but the granite on the contrary, softer and less perfectly crystallised near the junction.[1] Although the granite is incumbent in the above section (fig. 628), we cannot assume that it overflowed the strata, for the disturbances of the rocks are so great in this part of the Alps that their original position is often inverted.

Plutonic rocks of Carboniferous Period.—The granite of Dartmoor, in Devonshire, was formerly supposed to be one of the most ancient of the plutonic rocks, but is now ascertained to be posterior in date to the culm-measures of that county, which from their position, and as containing true coal-plants, are now known to be members of the true Carboniferous series. This granite, like the hornblendic granite of Christiania, has broken through the stratified formations, on the north-west side of Dartmoor, the successive members of the culm-measures abutting against the granite, and becoming metamorphosed as they approach it. These strata are also penetrated by granite veins, and plutonic dikes, called 'elvans.'[2] The granite of Cornwall is probably of the same date, and, therefore, as modern as the Carboniferous strata, if not newer.

Plutonic rocks of Silurian Period.—It has long been known that a very ancient granite near Christiania, in Norway, is posterior in date to the Lower Silurian strata of that region, although its exact position in the Palæozoic series cannot be defined. Von Buch first announced, in 1813, that it was of newer origin than certain limestones containing orthocerata and trilobites. The proofs consist in the penetration of granite veins into the shale and limestone, and the alteration of the strata, for a considerable distance from the point of contact, both of these veins and the central mass from which they emanate. (See p. 562.) Von Buch supposed that the plutonic rock alternated with the fossiliferous strata, and that large masses of granite were sometimes incumbent upon the strata; but this idea was erroneous, and arose from the fact that the beds of shale and limestone often dip towards the granite up to the point of contact, appearing as if they would pass under it in mass, as at *a*, fig. 629, and then again on the opposite side of the same mountain, as at *b*, dip away from the same granite. When the junctions, however, are carefully examined, it is found that the plutonic rock intrudes itself in veins and nowhere covers the fossiliferous strata in large overlying masses, as is so commonly the case with trappean formations.[1]

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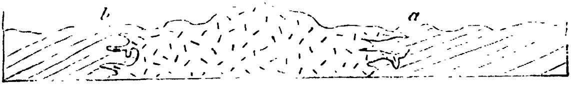
[1] Élie de Beaumont, Sur les Montagnes de l'Oisans, &c. Mém. de la Soc. d'Hist. Nat. de Paris, tom. v.

[2] Proceed. Geol. Soc., vol. ii. p. 562; and Trans., 2nd ser. vol. v. p. 686.

Fig. 629.

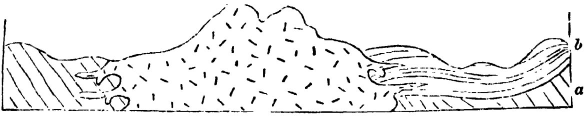


Silurian. Granite. Silurian strata.

Now this granite, which is more modern than the Silurian strata of Norway, also sends veins in the same country into an ancient formation of gneiss; and the relations of the plutonic rock and the gneiss, at their junction, are full of interest when we duly consider the wide difference of epoch which must have separated their origin.

The length of this interval of time is attested by the following facts:—The fossiliferous, or Silurian, beds rest unconformably upon the truncated edges of the gneiss, the inclined strata of which had been denuded before the sedimentary beds were superimposed (see fig. 630). The signs of denudation are twofold; first, the surface of the gneiss is seen occasionally, on the removal of the newer beds containing organic remains, to be worn and smoothed; secondly, pebbles of gneiss have been found in some of these Silurian strata. Between the origin, therefore, of the gneiss and the granite there intervened, first, the period when the strata of gneiss were denuded; secondly,

Fig. 630.



Gneiss. Granite. Gneiss.

Granite sending veins into Silurian strata and gneiss. Christiania, Norway.
a. Inclined gneiss. *b*. Silurian strata.

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[1] See the Gæa Norvegica and other works of Keilhau, with whom I examined this country.

the period of the deposition of the Silurian deposits upon the denuded and inclined gneiss *a*. Yet the granite produced after this long interval is often so intimately blended with the ancient gneiss, at the point of junction, that it is impossible to draw any other than an arbitrary line of separation between them; and where this is not the case, tortuous veins of granite pass freely through gneiss, ending sometimes in threads, as if the older rock had offered no resistance to their passage. These appearances may probably be due to hydrothermal action (see below, p. 583). I shall merely observe in this place that had such junctions alone been visible, and had we not learnt, from other sections, how long a period elapsed between the consolidation of the gneiss, and the injection of this granite, we might have suspected that the gneiss was scarcely solidified, or had not yet assumed its complete metamorphic character when invaded by the plutonic rock. From this example we may learn how impossible it is to conjecture whether certain granites in Scotland, and other countries, which send veins into gneiss and other metamorphic rocks, are primary, or whether they may not belong to some secondary or tertiary period.

Oldest granites.—It is not half a century since the doctrine was very general that all granitic rocks were *primitive*, that is to say, that they originated before the deposition of the first sedimentary strata, and before the creation of organic beings (see above, p. 10). But so greatly are our views now changed, that we find it no easy task to point out a single mass of granite demonstrably more ancient than known fossiliferous deposits. Could we discover some Laurentian strata resting immediately on granite, there being no alterations at the point of contact, nor any intersecting granitic veins, we might then affirm the plutonic rock to have originated before the oldest known fossiliferous strata. Still it would be presumptuous, as we have already pointed out (p. 462), to suppose that when a small part only of the globe has been investigated, we are acquainted with the oldest fossiliferous strata in the crust of our planet. Even when these are found we cannot assume that there never were any antecedent strata containing organic remains, which may have become metamorphic. If we find pebbles of granite in a conglomerate of the Lower Laurentian system, we may then feel assured that the parent granite was formed before the Laurentian formation. But if the incumbent strata be merely Cambrian or Silurian, the fundamental granite, although of high antiquity, may be posterior in date to *known* fossiliferous formations.

CHAPTER XXXIII.

METAMORPHIC ROCKS.

General character of metamorphic rocks—Gneiss—Hornblende-schist—Serpentine—Mica-schist—Clay-slate—Quartzite—Chlorite-schist—Metamorphic limestone—Origin of the metamorphic strata—Their stratification—Fossiliferous strata near intrusive masses of granite converted into rocks identical with different members of the metamorphic series—Arguments hence derived as to the nature of plutonic action—Hydrothermal action, or the influence of steam and gases in producing metamorphism—Objections to the metamorphic theory considered.

We have now considered three distinct classes of rocks: first, the aqueous, or fossiliferous; secondly, the volcanic; and thirdly, the plutonic; and it remains for us to examine those crystalline (or hypogene) strata to which the name of *metamorphic* has been assigned. The last-mentioned term expresses, as before explained, a theoretical opinion that such strata, after having been deposited from water, acquired, by the influence of heat and other causes, a highly crystalline texture. They who still question this opinion may call the rocks under consideration the stratified hypogene formations or crystalline schists.

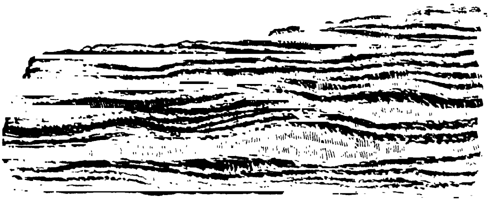
These rocks, when in their characteristic or normal state, are wholly devoid of organic remains, and contain no distinct fragments of other rocks, whether rounded or angular. They sometimes break out in the central parts of mountain chains, but in other cases extend over areas of vast dimensions, occupying, for example, nearly the whole of Norway and Sweden, where, as in Brazil, they appear alike in the lower and higher grounds. However crystalline these rocks may become in certain regions, they never, like granite or trap, send veins into contiguous formations. In Great Britain, those members of the series which approach most nearly to granite in their composition, as gneiss, mica-schist, and hornblende-schist, are chiefly found in the country north of the rivers Forth and Clyde.

Many attempts have been made to trace a general order of succession or superposition in the members of this family; clay-slate, for example, having been often supposed to hold invariably a higher geological position than mica-schist, and mica-schist to overlie gneiss. But although such an order may prevail throughout limited districts, it is by no means universal. To this subject, however, I shall again revert, in Chapter XXXV., where the chronological relations of the metamorphic rocks are pointed out.

Principal metamorphic rocks.—The following may be enumerated as the principal members of the metamorphic class :—gneiss, mica-schist, hornblende-schist, clay-slate, chlorite-schist, hypogene or metamorphic limestone, and certain kinds of quartz-rock or quartzite.

Gneiss.—The first of these, gneiss, may be called stratified—or by those who object to that term, foliated—granite, being formed of the same materials as granite, namely, felspar, quartz, and mica. In the specimen here figured, the white layers consist almost exclusively of granular felspar, with here and there a speck of mica and grain of quartz. The dark layers are composed of grey quartz and black mica, with occasionally a grain of felspar intermixed. The rock splits most easily in the plane of these darker layers, and the surface thus exposed is almost entirely covered with shining spangles of mica. The accompanying quartz, however, greatly predominates in quantity, but the most ready cleavage is determined by the abundance of mica in certain parts of the dark layer. Instead of consisting of these thin laminæ, gneiss is sometimes simply divided into thick beds, in which the mica has only a slight degree of parallelism to the planes of stratification.

Fig. 631.



Fragment of gneiss, natural size ; section made at right angles to the planes of foliation.

Hand specimens may often be obtained from such gneiss which are undistinguishable from granite, affording an argument to which we shall allude in the concluding part of this chapter, in favour of those who regard all granite and syenite not as igneous rocks, but as aqueous formations so altered as to have lost all signs of their original stratified arrangement. Gneiss in geology is commonly used to designate not merely stratified and foliated rocks having the same component materials as granite or syenite, but also in a wider sense to embrace the formation with which other members of the metamorphic series such as hornblende-schist may alternate, and which are then considered subordinate to the true gneiss.

The different varieties of rock allied to gneiss, into which felspar enters as an essential ingredient, will be understood by referring to what was said of granite. Thus, for example, hornblende may be superadded to mica, quartz, and felspar, forming a hornblendic or syenitic gneiss ; or talc may be substituted for mica, constituting talcose gneiss (called stratified protogine by the French), a rock composed of felspar, quartz, and talc, in distinct crystals or grains.

Hornblende-schist is usually black, and composed principally of hornblende, with a variable quantity of felspar, and sometimes grains of quartz. When the hornblende and felspar are in nearly equal quantities, and the rock is not slaty, it corresponds in character with the greenstones of the trap family, and has been called 'primitive greenstone.' It may be termed hornblende rock or amphibolite. Some of these hornblendic masses may really have been volcanic rocks, which have since assumed a more crystalline or metamorphic texture.

Actinolite schist is a slaty foliated rock, composed chiefly of actinolite, an emerald-green mineral (allied to hornblende), which occurs in slender prismatic crystals, sometimes forming radiating groups, with some admixture of quartz, mica, and garnet.

Serpentine is a hydrated silicate of magnesia in which there is sometimes from 30 to 40 per cent. of magnesia. It is a rock of a green colour, sometimes rendered of a mottled red and dark brown by the presence of hematite. It enters largely into the composition of a trap dike cutting through Old Red Sandstone in Forfarshire, and in that case is probably an altered basaltic dike which had contained much olivine. The theory of its having been originally a volcanic product subsequently altered by metamorphism may at first sight seem inconsistent with its occurrence in large and regularly stratified masses in the metamorphic series in Scotland, as in Aberdeenshire. But it has been suggested in explanation that such serpentine may have been originally regularly-bedded trap tuff, and volcanic breccia, with much olivine, which would still retain a stratified appearance after their conversion into a metamorphic rock.

Mica-schist, or *Micaceous schist*, is, next to gneiss, one of the most abundant rocks of the metamorphic series. It is slaty, essentially composed of mica and quartz, the mica sometimes appearing to constitute the whole mass. Beds of pure quartz also occur in this formation. In some districts, garnets in regular twelve-sided crystals form an integrant part of mica-schist. This rock passes by insensible gradations into clay-slate.

Clay-slate—Argillaceous schist—Argillite.—This rock sometimes resembles an indurated clay or shale. It is for the most part extremely fissile, often affording good roofing-slate. Occasionally it derives a shining and silky lustre from the minute particles of mica or talc which it contains. It varies from greenish or bluish-grey to a lead colour ; and it may be said of this, more than of any other schist, that it is common to the metamorphic and fossiliferous series, for some clay-slates taken from each division would not be distinguishable by mineral characters alone. It is not uncommon to meet with an argillaceous rock having the same composition, without the slaty cleavage, which may be called argillite.

Chlorite-schist is a green slaty rock, in which chlorite is abundant in foliated plates, usually blended with minute grains of quartz, or sometimes with felspar or mica ; often associated with and graduating into gneiss and clay-slate.

Quartzite, or *Quartz rock*, is an aggregate of grains of quartz which are either in minute crystals, or in many cases slightly rounded, occurring in regular strata associated with gneiss or other metamorphic rocks. Compact quartz, like that so frequently found in veins, is also found together with granular quartzite. Both of these alternate with gneiss or mica-schist, or pass into those rocks by the addition of mica, or of felspar and mica.

Crystalline or *Metamorphic limestone.*—This rock, called by the earlier geologists *primary limestone*, is sometimes a white crystalline granular marble, which when in thick beds can be used in sculpture ; but more frequently it occurs in thin beds, forming a foliated schist much resembling in colour and arrangement certain varieties of gneiss and mica-schist. When it alternates with these rocks, it often contains some crystals of mica, and occasionally quartz, felspar, hornblende, talc, chlorite, garnet, and other minerals. It enters sparingly into the structure of the metamorphic districts of Norway, Sweden, and Scotland, but is largely developed in the Alps.

Origin of the Metamorphic strata.—Having said thus much of the mineral composition of the metamorphic rocks, I may combine what remains to be said of their structure and history with an account of the opinions entertained of their probable origin. At the same time, it may be well to forewarn the reader that we are here entering upon ground of controversy, and soon reach the limits where positive induction ends, and beyond which we can only indulge in speculations. It was once a favourite doctrine, and is still maintained by many, that these rocks owe their crystalline texture, their want of all signs of a mechanical origin, or of fossil contents, to a peculiar and nascent condition of the planet at the period of their formation. The arguments in refutation of this hypothesis will be more fully considered when I show, in Chapter XXXV., to how many different ages the metamorphic formations are referable, and how gneiss, mica-schist, clay-slate, and hypogene limestone (that of Carrara, for example) have been formed, not only since the first introduction of organic beings into this planet, but even long after many distinct races of plants and animals had flourished and passed away in succession.

The doctrine respecting the crystalline strata, implied in the name metamorphic, may properly be treated of in this place; and we must first enquire whether these rocks are really entitled to be called stratified in the strict sense of having been originally deposited as sediment from water. The general adoption by geologists of the term stratified, as applied to these rocks, sufficiently attests their division into beds very analogous, at least in form, to ordinary fossiliferous strata. This resemblance is by no means confined to the existence in both occasionally of a laminated structure, but extends to every kind of arrangement which is compatible with the absence of fossils, and of sand, pebbles, ripple-mark, and other characters which the metamorphic theory supposes to have been obliterated by plutonic action. Thus, for example, we behold alike in the crystalline and fossiliferous formations an alternation of beds varying greatly in composition, colour, and thickness. We observe, for instance, gneiss alternating with layers of black hornblende-schist, or of green chlorite-schist, or with granular quartz, or limestone; and the interchange of these different strata may be repeated for an indefinite number of times. In the like manner, mica-schist alternates with chlorite-schist, and with beds of pure quartz or of granular limestone. We have already seen that, near the immediate contact of granitic veins and volcanic dikes, very extraordinary alterations in rocks have taken place, more especially in the neighbourhood of granite. It will be useful here to add other illustrations, showing that a texture undistinguishable from that which characterises the more crystalline metamorphic formations has actually been superinduced in strata once fossiliferous.

Fossiliferous strata rendered metamorphic by intrusive masses of Granite.—In the southern extremity of Norway there is a large district, on the west side of the fiord of Christiania, which I visited in 1837 with the late Professor Keilhau, in which hornblendic granite protrudes in mountain masses through fossiliferous strata, and usually sends veins into them at the point of contact. The stratified rocks, replete with shells and zoophytes, consist chiefly of shale, limestone, and some sandstone, and all these are invariably altered near the granite for a distance of from 50 to 400 yards. The aluminous shales are hardened, and have become flinty. Sometimes they resemble jasper. Ribboned jasper is produced by the hardening of alternate layers of green and chocolate-coloured schist, each stripe faithfully representing the original lines of stratification. Nearer the granite the schist often contains crystals of hornblende, which are even met with in some places for a distance of several hundred yards from the junction; and this black hornblende is so abundant that eminent geologists, when passing through the country, have confounded it with the ancient hornblende-schist, subordinate to the great gneiss formation of Norway. Frequently, between the granite and the hornblende slate, above-mentioned, grains of mica and crystalline felspar appear in the schist, so that rocks resembling gneiss and mica-schist are produced. Fossils can rarely be detected in these schists, and they are more completely effaced in proportion to the more crystalline texture of the beds, and their vicinity to the granite. In some places the siliceous matter of the schist becomes a granular quartzite; and when hornblende and mica are added, the altered rock loses its stratification, and passes into a kind of granite. The limestone, which at points remote from the granite is of an earthy texture and blue colour, and often abounds in corals, becomes a white granular marble near the granite, sometimes siliceous, the granular structure extending occasionally upwards of 400 yards from the junction; the corals being for the most part obliterated, though sometimes preserved, even in the white marble. Both the altered limestone and hardened slate contain garnets in many places, also ores of iron, lead, and copper, with some silver. These alterations occur equally, whether the granite invades the strata in a line parallel to the general strike of the fossiliferous beds, or in a line at right angles to their strike, both of which modes of junction will be seen by the accompanying ground plan (fig. 632).[1]

The granite of Cornwall sends forth veins into a coarse argillaceous-schist, provincially termed killas. This killas is converted into hornblende-schist near the contact with the veins. These appearances are well seen at the junction of the granite and killas, in St. Michael's Mount, a small island nearly 300 feet high, situated in the bay, at a distance of about three miles from Penzance. The granite of Dartmoor, in Devonshire, says Sir H. De la Beche, has intruded itself into the carboniferous slate and slaty sandstone, twisting and contorting the strata, and sending veins into them. Hence some of the slate rocks have become 'micaceous; others more indurated, and with the characters of mica-slate and gneiss; while others again appear converted into a hard zoned rock strongly impregnated with felspar.'[1]

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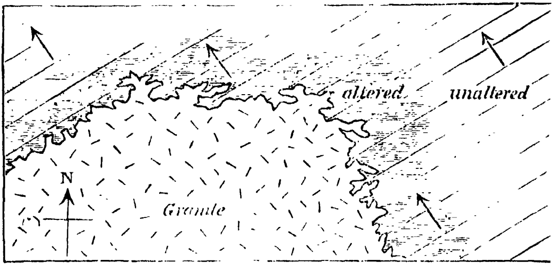
[1] Keilhau, Gæa Norvegica, pp. 61–63.

Fig. 632.



Ground-plan of altered slate and limestone near granite. Christiania.
The arrows indicate the dip, and the oblique lines the strike of the beds.

Nowhere, however, are the phenomena of local metamorphism more beautifully illustrated than in the Western Isles of Scotland. Mr. Judd has pointed out that in this neighbourhood great masses of granite and gabbro were, during the Tertiary period, thrust through the various Palæozoic and Secondary strata, and in the vicinity of the junctions of the igneous and the sedimentary masses the most instructive examples of metamorphism may be witnessed. Thus Lias limestones crowded with fossil shells are found losing, as we approach the igneous rocks, all traces of their organic remains, and at last passing into a highly crystalline or saccharoid marble suitable for statuary purposes; similarly clays and limestones, under like conditions, are also found to be deprived of every trace of the organic structures in them and to graduate into indurated slaty rock and quartzite respectively, while the felspathic sandstones of the Cambrian are altered to a highly micaceous schistose rock.

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[1] Geol. Manual, p. 479.

We learn from the investigations of M. Dufrénoy, that in the eastern Pyrenees there are mountain masses of granite posterior in date to the formations called lias and chalk of that district, and that these fossiliferous rocks are greatly altered in texture, and often charged with iron-ore, in the neighbourhood of the granite. Thus in the environs of St. Martin, near St. Paul de Fénouillet, the chalky limestone becomes more crystalline and saccharoid as it approaches the granite, and loses all trace of the fossils which it previously contained in abundance. At some points, also, it becomes dolomitic, and filled with small veins of carbonate of iron, and spots of red iron-ore. At Rancié the lias nearest the granite is not only filled with iron-ore, but charged with pyrites, tremolite, garnet, and a new mineral somewhat allied to felspar, called from the place in the Pyrenees where it occurs 'couzeranite.'

The Lower Silurian strata of the Highlands, which are throughout their whole mass changed into various metamorphic rocks, are found near their junction with the intrusive masses of the Grampian Mountains, to have undergone a further metamorphism of a local character.

We have seen that sedimentary rocks in the immediate proximity of great igneous intrusions are found to have undergone great induration, while along their planes of bedding or cleavage the development of various crystalline minerals has frequently taken place. The similarity of the rocks thus formed to many of the foliated or schistose rocks suggests that the latter may have been in all cases produced from pre-existing strata, by the action of analogous chemical forces, operating on a more extended scale. Thus gneiss and mica-schist may be nothing more than altered micaceous and argillaceous sandstones, granular quartzite may have been derived from siliceous sandstone, and compact quartzite may be the last stage of alteration of the same materials. Similarly, clay-slate may be altered shale, and granular marble may have originated in the form of ordinary limestone, replete with shells and corals, which have since been obliterated; and, lastly, calcareous sands and marls may have been changed into impure crystalline limestones.

The anthracite and plumbago associated with hypogene rocks may have been coal; for not only is coal converted into anthracite in the vicinity of some trap dikes, but we have seen that a like change has taken place generally even far from the contact of igneous rocks, in the disturbed region of the Appalachians. At Worcester, in the state of Massachusetts, 45 miles due west of Boston, a bed of plumbago and impure anthracite occurs, interstratified with mica-schist. It is about 2 feet in thickness, and has been made use of both as fuel and in the manufacture of lead pencils. At the distance of 30 miles from the plumbago, there occurs, on the borders of Rhode Island, an impure anthracite in slates containing impressions of coal-plants of the genera *Pecopteris*, *Neuropteris*, *Calamites*, &c. This anthracite is intermediate in character between that of Pennsylvania and the plumbago of Worcester, in which last the gaseous or volatile matter (hydrogen, oxygen, and nitrogen) is to the carbon only in the proportion of 3 per cent. After traversing the country in various directions, I came to the conclusion that the carboniferous shales or slates with anthracite and plants, which in Rhode Island often pass into mica-schists, have at Worcester assumed a perfectly crystalline and metamorphic texture; the anthracite having been nearly transmuted into that state of pure carbon which is called plumbago or graphite.[1]

Now the alterations above described as superinduced in rocks by volcanic dikes and granite veins prove incontestably that powers exist in nature capable of transforming fossiliferous into crystalline strata, a very few simple elements constituting the component materials uncommon to both classes of rocks. These elements, which are enumerated in our Table, p. 498, may be made to form new combinations by what has been termed plutonic action, or those chemical changes which are no doubt connected with the passage of heat, and usually heated steam and waters, through the strata.

Hydrothermal action, or the influence of Steam and Gases in producing Metamorphism.—The experiments of Gregory Watt, in fusing rocks in the laboratory, and allowing them to consolidate by slow cooling, prove distinctly that a rock need not be perfectly melted in order that a re-arrangement of its component particles should take place, and a partial crystallisation ensue.[2] We may easily suppose, therefore, that all traces of shells and other organic remains may be destroyed; and that new chemical combinations may arise, without the mass being so fused as that the lines of stratification should be wholly obliterated. We must not, however, imagine that heat alone, such as may be applied to a stone in the open air, can constitute all that is comprised in plutonic action. We know that volcanos in eruption not only emit fluid lava, but give off steam and other heated gases, which rush out in enormous volume, for days, weeks, or years continuously, and are even disengaged from lava during its consolidation.

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[1] See Lyell, Quart. Geol. Journ., vol. i. p. 199.

[2] Phil. Trans., 1804.

We also know that long after volcanoes have spent their force, hot springs continue for ages to flow out at various points in the same area. In regions also subject to violent earthquakes such springs are frequently observed issuing from rents, usually along lines of fault or displacement of the rocks. These thermal waters are most commonly charged with a variety of mineral ingredients, and they retain a remarkable uniformity of temperature from century to century. A like uniformity is also persistent in the nature of the earthy, metallic, and gaseous substances with which they are impregnated. It is well ascertained that springs, whether hot or cold, charged with carbonic acid, and especially with hydrofluoric acid, which is often present in small quantities, are powerful causes of decomposition and chemical reaction in rocks through which they percolate.

The changes which Daubrée has shown to have been produced by the alkaline waters of Plombières in the Vosges, are more especially instructive.[1] These waters have a heat of 160° F., or an excess of 109° above the average temperature of ordinary springs in that district. They were conveyed by the Romans to baths through long conduits or aqueducts. The foundations of some of their works consisted of a bed of concrete made of lime, fragments of brick and sandstone. Through this and other masonry the hot waters have been percolating for centuries, and have given rise to various zeolites—apophyllite and chabazite among others; also to calcareous spar, arragonite, and fluor spar, together with siliceous minerals, such as opal—all found in the interspaces of the bricks and mortar, or constituting part of their re-arranged materials. The quantity of heat brought into action in this instance in the course of 2,000 years has, no doubt, been enormous, but the intensity of it developed at any one moment has been always inconsiderable.

From these facts and from the experiments and observations of Sénarmont, Daubrée, Delesse, Scheerer, Sorby, Sterry Hunt, and others, we are led to infer that when there are large volumes of matter in the bowels of the earth, containing water and various acids intensely heated under enormous pressure, these subterranean fluid masses will gradually part with their heat by the escape of steam and various gases through fissures, producing hot springs; or by the passage of the same through the pores of the overlying and injected rocks. Even the most compact rocks may be regarded, before they have been exposed to the air and dried, in the light of sponges filled with water. According to the experiments of Henry, water, under an hydrostatic pressure of 96 feet, will absorb three times as much carbonic acid gas as it can under the ordinary pressure of the atmosphere. There are other gases, as well as the carbonic acid, which water absorbs, and more rapidly in proportion to the amount of pressure. Although the gaseous matter first absorbed would soon be condensed, and part with its heat, yet the continual arrival of fresh supplies from below might, in the course of ages, cause the temperature of the water, and with it that of the containing rock, to be materially raised; the water acts not only as a vehicle of heat, but also by its affinity for various silicates, which, when some of the materials of the invaded rocks are decomposed, form quartz, felspar, mica, and other minerals. As for quartz, it can be produced under the influence of heat by water holding alkaline silicates in solution, as in the case of the Plombières springs. The quantity of water required, according to Daubrée, to produce great transformations in the mineral structure of rocks, is very small. As to the heat required, silicates may be produced in the moist way at about incipient red heat, whereas to form the same in the dry way would require a much higher temperature.

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[1] Daubrée, Sur le Métamorphisme. Paris, 1860.

M. Fournet, in his description of the metalliferous gneiss near Clermont, in Auvergne, states that all the minute fissures of the rock are quite saturated with free carbonic acid gas; which gas rises plentifully from the soil there and in many parts of the surrounding country. The various elements of the gneiss, with the exception of the quartz, are all softened; and new combinations of the acid with lime, iron, and manganese are continually in progress.[1]

The power of subterranean gases is well illustrated by the stufas of St. Calogero in the Lipari Islands, where the horizontal strata of tuff forming cliffs 200 feet high, have been discoloured in places by the jets of steam often above the boiling point, called 'stufas,' issuing from the fissures; and similar instances are recorded by M. Virlet of corrosion of rocks near Corinth, and by Dr. Daubeny of decomposition of trachytic rocks by sulphuretted hydrogen and muriatic acid gases in the Solfatara, near Naples. In all these instances it is clear that the gaseous fluids must have made their way through vast thicknesses of porous or fissured rocks, and their modifying influence may spread through the crust for thousands of yards in thickness.

It has been urged as an argument against the metamorphic theory, that rocks have a small power of conducting heat, and it is true that when dry, and in the air, they differ remarkably from metals in this respect. The syenite of Norway, as we have seen, p. 561, has sometimes altered fossiliferous strata both in the direction of their dip and strike for a distance of a quarter of a mile, but the theory of gneiss and mica-schist above proposed requires us to imagine that the same influence has extended through strata miles in thickness. Professor Bischoff has shown what changes may be superinduced, on black marble and other rocks, by the steam of a hot spring having a temperature of no more than 133° to 167° Fahr., and we are becoming more and more acquainted with the prominent part which water is playing in distributing the heat of the interior through mountain masses of incumbent strata, and of introducing into them various mineral elements in a fluid or gaseous state. Such facts may induce us to consider whether many granites and other rocks of that class may not sometimes represent merely the extreme of a similar slow metamorphism. But, on the other hand, the heat of lava in a volcanic crater when it is white and glowing like the sun must convince us that the temperature of a column of such a fluid at the depth of many miles, exceeds any heat which can ever be witnessed at the surface. That large portions of the plutonic rocks had been formed under the influence of such intense heat is in perfect accordance with their great volume, uniform composition, and absence of stratification. The forcing also of veins into contiguous stratified or schistose rocks is a natural consequence of the hydrostatic pressure to which columns of molten matter many miles in height must give rise.

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[1] See Principles, *Index*, 'Carbonated Springs,' &c.

Objections to the metamorphic theory considered.—It has been objected to the metamorphic theory that the crystalline schists contain a considerable proportion of potash and soda, whilst the sedimentary strata out of which they are supposed to have been formed, are usually wanting in alkaline matter. But this reasoning proceeds on mistaken data, for clay, marl, shale, and slate often contain a considerable proportion of alkali, so much so as to make them frequently unfit to be burnt into bricks or pottery, and the Old Red Sandstone in Forfarshire and other parts of Scotland derived from disintegration of granite, contains much triturated felspar rich in potash. In the common salt by which strata are often largely impregnated, as in Patagonia, much soda is present, and potash enters largely into the composition of fossil sea-weeds, and recent analysis has also shown that the carboniferous strata in England, the Upper and Lower Silurian in East Canada, and the oldest clay-slates in Norway, all contain as much alkali as is generally present in metamorphic rocks.

Another objection has been derived from the alternation of highly crystalline strata with others less crystalline. The heat, it is said, in its ascent from below, must have traversed the less altered schists before it reached a higher and more crystalline bed. In answer to this, it may be observed, that if a number of strata differing greatly in composition from each other be subjected to equal quantities of heat, or hydrothermal action, there is every probability that some will be much more fusible or soluble than others. Some, for example, will contain soda, potash, lime, or some other ingredient capable of acting as a flux or solvent; while others may be destitute of the same elements, and so refractory as to be very slightly affected by the same causes. Nor should it be forgotten that, as a general rule, the less crystalline rocks do really occur in the upper, and the more crystalline in the lower part of each metamorphic series.

CHAPTER XXXIV.

METAMORPHIC ROCKS—*continued*.

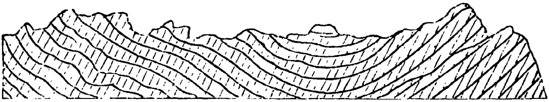
Definition of slaty cleavage and joints—Supposed causes of these structures—Crystalline theory of cleavage—Mechanical theory of cleavage—Condensation and elongation of slate rocks by lateral pressure—Lamination of some volcanic rocks due to motion—Whether the foliation of the crystalline schists be usually parallel with the original planes of stratification—Examples in Norway and Scotland—Causes of irregularity in the planes of foliation.

We have already seen that chemical forces of great intensity have frequently acted upon sedimentary and fossiliferous strata long subsequently to their consolidation, and we may next enquire whether the component minerals of the altered rocks usually arrange themselves in planes parallel to the original planes of stratification, or whether, after crystallisation, they more commonly take up a different position.

In order to estimate fairly the merits of this question, we must first define what is meant by the terms cleavage and foliation. There are four distinct forms of structure exhibited in rocks, namely, stratification, joints, slaty cleavage, and foliation; and all these must have different names, even though there be cases where it is impossible, after carefully studying the appearances, to decide upon the class to which they belong.

Slaty cleavage.—Professor Sedgwick, whose essay 'On the Structure of large Mineral Masses' first cleared the way towards a better understanding of this difficult subject, observes, that joints are distinguishable from lines of slaty cleavage in this, that the rock intervening between two joints has no tendency to cleave in a direction parallel to the planes of the joints, whereas a rock is capable of indefinite subdivision in the direction of its slaty cleavage. In cases where the strata are curved, the planes of cleavage are still perfectly parallel. This has been observed in the slate rocks of part of Wales (see fig. 633), which consist of a hard greenish slate. The true bedding is there indicated by a number of parallel stripes, some of a lighter and some of a darker colour than the general mass. Such stripes are found to be parallel to the true planes of stratification, wherever these are manifested by ripple-mark, or by beds containing peculiar organic remains. Some of the contorted strata are of a coarse mechanical structure, alternating with fine-grained crystalline chloritic slates, in which case the same slaty cleavage extends through the coarser and finer beds, though it is brought out in greater perfection in proportion as the materials of the rock are fine and homogeneous. It is only when these are very coarse that the cleavage planes entirely vanish. In the Welsh hills these planes are usually inclined at a very considerable angle to the planes of the strata, the average angle being as much as from 30° to 40°. Sometimes the cleavage planes dip towards the same point of the compass as those of stratification, but often to opposite points.[1] The cleavage, as represented in fig. 633, is generally constant over the whole of any area affected by one great set of disturbances, as if the same lateral pressure which caused the crumpling up of the rock along parallel, anticlinal, and synclinal axes caused also the cleavage.

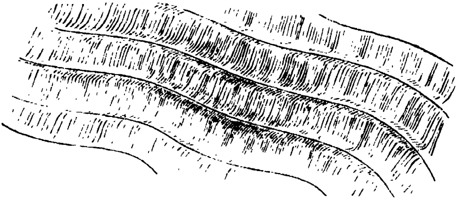
Fig. 633.



Parallel planes of cleavage intersecting curved strata. (Sedgwick.)

Professor McKenny Hughes remarks, that where a rough cleavage cuts flagstones at a considerable angle to the planes of stratification, the rock often splits into large slabs, across which the lines of bedding are frequently seen, but when the cleavage planes approach within about 15° of stratification, the rock is apt to split along the lines of bedding. He has also called my attention to the fact that subsequent movements in a cleaved rock sometimes drag and bend the cleavage planes along

Fig. 634.



Section in Lower Silurian slates of Cardiganshire, showing the cleavage planes bent along the junction of the beds. (T. McK. Hughes.)

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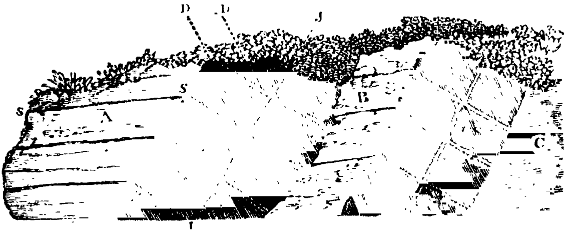
[1] Geol. Trans., 2nd series, vol. iii. p. 461.

the junction of the beds in the manner indicated in the annexed figure.

Jointed structure.—In regard to joints, they are natural fissures which often traverse rocks in straight and well-determined lines. They afford to the quarryman, as Sir R. Murchison observes, when speaking of the phenomena, as exhibited in Shropshire and the neighbouring counties, the greatest aid in the extraction of blocks of stone; and, if a sufficient number cross each other, the whole mass of rock is split into symmetrical blocks. The faces of the joints are for the most part smoother and more regular than the surfaces of true strata. The joints are straight-cut chinks, sometimes slightly open, and often passing, not only through layers of successive deposition, but also through balls of limestone or other matter, which have been formed by concretionary action since the original accumulation of the strata, and in the case of conglomerates even through quartz pebbles. Such joints, therefore, must often have resulted from one of the last changes superinduced upon sedimentary deposits.[1]

In the annexed diagram (fig. 635), the flat surfaces of rock A, B, C, represent exposed faces of joints, to which the walls of other joints, J J, are parallel. S S are the lines of stratification; D D are lines of slaty cleavage, which intersect the rock at a considerable angle to the planes of stratification.

Fig. 635.



Stratification, joints, and cleavage.
(From Murchison's 'Silurian System,' p. 245.)

In the Swiss and Savoy Alps, as Mr. Bakewell has remarked, enormous masses of limestone are cut through so regularly by nearly vertical partings, and these joints are often so much more conspicuous than the seams of stratification, that an inexperienced observer will almost inevitably confound them, and suppose the strata to be perpendicular in places where in fact they are almost horizontal.[2]

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[1] Silurian System, p. 246.

[2] Introduction to Geology, chap. iv.

In many countries where masses of basalt rest on sandstone, the aqueous rock has for the distance of several feet from the point of junction assumed a columnar structure similar to that of the trap. In like manner some hearthstones, after exposure to the heat of a furnace without being melted, have become prismatic. Certain crystals also acquire by the application of heat a new internal arrangement, so as to break in a new direction, their external form remaining unaltered.

Crystalline theory of cleavage.—Professor Sedgwick, speaking of the planes of slaty cleavage, where they are decidedly distinct from those of sedimentary deposition, declared in the essay before alluded to, his opinion that no retreat of parts, no contraction in the dimensions of rocks in passing to a solid state, can account for the phenomenon. He accordingly referred it to crystalline or polar forces acting simultaneously, and somewhat uniformly, in given directions, on large masses having a homogeneous composition.

Sir John Herschel, in allusion to slaty cleavage, has suggested, 'that if rocks have been so heated as to allow a commencement of crystallisation,—that is to say, if they have been heated to a point at which the particles can begin to move amongst themselves, or at least on their own axes, some general law must then determine the position in which these particles will rest on cooling. Probably, that position will have some relation to the direction in which the heat escapes. Now, when all, or a majority of particles of the same nature have a general tendency to one position, that must of course determine a cleavage-plane. Thus we see the infinitesimal crystals of fresh precipitated sulphate of barytes, and some other such bodies, arrange themselves alike in the fluid in which they float; so as, when stirred, all to glance with one light, and give the appearance of silky filaments. Some sorts of soap, in which insoluble margarates[1] exist, exhibit the same phenomenon when mixed with water; and what occurs in our experiments on a minute scale may occur in nature on a great one.'[2]

Mechanical theory of Cleavage.—Professor Phillips has remarked that in some slaty rocks the form of the outline of fossil shells and trilobites has been much changed by distortion, which has taken place in a longitudinal, transverse, or oblique direction. This change, he adds, seems to be the result of a 'creeping movement' of the particles of the rock along the planes of cleavage, its direction being always uniform over the same tract of country, and its amount in space being sometimes measurable, and being as much as a quarter or even half an inch.[3] Mr. D. Sharpe, following up the same line of enquiry, came to the conclusion that the present distorted forms of the shells in certain British slate rocks may be accounted for by supposing that the rocks in which they are imbedded have undergone compression in a direction perpendicular to the planes of cleavage, and a corresponding expansion in the direction of the dip of the cleavage.[4]

Subsequently (1853) Mr. Sorby demonstrated the great extent to which this mechanical theory is applicable to the slate rocks of North Wales and Devonshire,[5] districts where the amount of change in dimensions can be tested and measured by comparing the different effects exerted by lateral pressure on alternating beds of finer and coarser materials. Thus, for example, in the accompanying figure (fig. 636) it will be seen that the sandy bed *d f*, which has offered greater resistance, has been sharply contorted, while the fine-grained strata, *a*, *b*, *c*, have remained comparatively unbent. The points *d* and *f* in the stratum *d f* must have been originally four times as far apart as they are now. They have been forced so much nearer to each other, partly by bending, and partly by becoming elongated in the direction of what may be called the longer axes of their contortions, and lastly, to a certain small amount, by condensation. The chief result has obviously been due to the bending; but, in proof of elongation, it will be observed that the thickness of the bed *d f* is now about four times greater in

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[1] Margaric acid is an oleaginous acid, formed from different animal and vegetable fatty substances. A margarate is a compound of this acid with soda, potash, or some other base, and is so named from its pearly lustre.

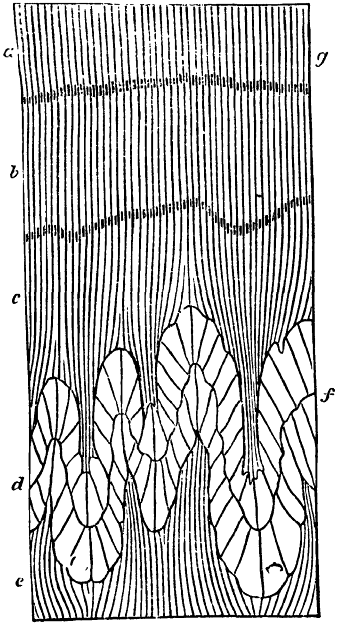
[2] Letter to the author, dated Cape of Good Hope, Feb. 20, 1836.

[3] Report, Brit. Assoc., Cork, 1843, Sect. p. 60.

[4] Quart. Geol. Journ., vol. iii. p. 87, 1847.

[5] On the Origin of Slaty Cleavage, by H. C. Sorby, Edinb. New. Phil. Journ. 1853, vol. lv. p. 137.

Fig. 636.



(Drawn by H. C. Sorby.)

Vertical section of slate rock in the cliffs near Ilfracombe, North Devon.

Scale one inch to one foot.

a, b, c, e. Fine-grained slates, the stratification being shown partly by lighter, or darker colours, and partly by different degrees of fineness in the grain.
d, f. A coarser-grained, light-coloured sandy slate, with less perfect cleavage.

Above the sandy bed *d f*, the stratum *c* is somewhat disturbed, while the next bed *b* is much less so, and *a* not at all; yet all these beds, *c*, *b*, and *a*, must have undergone an equal amount of pressure with *d*, the points *a* and *g* having approximated as much towards each other as have *d* and *f*. The same phenomena are also repeated in the beds below *d*, and might have been shown, had the section been extended downwards. Hence it appears that the finer beds have been squeezed into a fourth of the space they previously occupied, partly by condensation, or the closer packing of their ultimate particles (which has given rise to the great specific gravity of such slates), and partly by elongation in the line of the dip of the cleavage, of which the general direction is perpendicular to that of the pressure. 'These and numerous other cases in North Devon are analogous,' says Mr. Sorby, 'to what would occur if a strip of paper were included in a mass of some soft plastic material which would readily change its dimensions. If the whole were then compressed in the direction of the length of the strip of paper, it would be bent and puckered up into contortions, whilst the plastic material would readily change its dimensions without undergoing such contortions; and the difference in distance of the ends of the paper, as measured in a direct line or along it, would indicate the change in the dimensions of the plastic material.'

By microscopic examination of minute crystals, and by other observations, Mr. Sorby has come to the conclusion that the absolute condensation of the slate rocks amounts upon an average to about one half their original volume. Most of the scales of mica occurring in certain slates examined by Mr. Sorby lie in the plane of cleavage; whereas in a similar rock not exhibiting cleavage they lie with their longer axes in all directions. May not their position in the slates have been determined by the movement of elongation before alluded to? To illustrate this theory some scales of oxide of iron were mixed with soft pipe-clay in such a manner that they inclined in all directions. The dimensions of the mass were then changed artificially to a similar extent to what has occurred in slate rocks, and the pipe-clay was then dried and baked. When it was afterwards rubbed to a flat surface perpendicular to the pressure and in the line of elongation, or in a plane corresponding to that of the dip of cleavage, the particles were found to have become arranged in the same manner, as in natural slates, and the mass admitted of easy fracture into thin flat pieces in the plane alluded to, whereas it would not yield in that perpendicular to the cleavage.[1]

Dr. Tyndall, when commenting in 1856 on Mr. Sorby's experiments, observed that pressure alone is sufficient to produce cleavage, and that the intervention of plates of mica or scales of oxide of iron, or any other substances having flat surfaces, is quite unnecessary. In proof of this he showed experimentally that a mass of 'pure white wax after having been submitted to great pressure, exhibited a cleavage more clean than that of any slate-rock, splitting into laminæ of surpassing tenuity.'[2] He remarks that every mass of clay or mud is divided and subdivided by surfaces among which the cohesion is comparatively small. On being subjected to pressure, such masses yield and spread out in the direction of least resistance, small nodules become converted into laminæ separated from each other by surfaces of weak cohesion, and the result is that the mass cleaves at right angles to the line in which the pressure is exerted. In further illustration of this Professor Hughes remarks that concretions which in the undisturbed beds have their longer axes parallel to the bedding are, where the rock is much cleaved, frequently found flattened laterally, so as to have their longer axes parallel to the cleavage planes and at a considerable angle, even right angles, to their former position.

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[1] Sorby, as cited above, p. 741, note.

[2] Tyndall, View of the Cleavage of Crystals and Slate Rocks.

Mr. Darwin attributes the lamination and fissile structure of volcanic rocks of the trachytic series, including some obsidians in Ascension, Mexico, and elsewhere, to their having moved when liquid in the direction of the laminæ. The zones consist sometimes of layers of air-cells drawn out and lengthened in the supposed direction of the moving mass.[1]

Foliation of Crystalline Schists.—After studying, in 1835, the crystalline rocks of South America, Mr. Darwin proposed the term *foliation* for the laminæ or plates into which gneiss, mica-schist, and other crystalline rocks are divided. Cleavage, he observes, may be applied to those divisional planes which render a rock fissile, although it may appear to the eye quite or nearly homogeneous. Foliation may be used for those alternating layers or plates of different mineralogical nature of which gneiss and other metamorphic schists are composed.

That the planes of foliation of the crystalline schists in Norway accord very generally with those of original stratification is a conclusion long since espoused by Keilhau.[2] Numerous observations made by Mr. David Forbes in the same country (the best probably in Europe for studying such phenomena on a grand scale) confirm Keilhau's opinion. In Scotland, also, Mr. D. Forbes has pointed out a striking case where the foliation is identical with the lines of stratification in rocks well seen near Crianlorich on the road to Tyndrum, about 8 miles from Inverarnon in Perthshire. There is in that locality a blue limestone foliated by the intercalation of small plates of white mica, so that the rock is often scarcely distinguishable in aspect from gneiss or mica-schist. The stratification is shown by the large beds and coloured bands of limestone all dipping, like the folia, at an angle of 32 degrees N.E.[3] In stratified formations of every age we see layers of siliceous sand with or without mica, alternating with clay, with fragments of shells or corals, or with seams of vegetable matter, and we should expect the mutual attraction of like particles to favour the crystallisation of the quartz, or mica, or felspar, or carbonate of lime along the planes of original deposition, rather than in planes placed at angles of 20 or 40 degrees to those of stratification.

After a general examination of the metamorphic rocks of the Highlands, Sir Roderick Murchison and Mr. Geikie were led to the conclusion that throughout the whole district foliation is coincident with the stratification of the rocks, and not, as had been suggested by Mr. Daniel Sharpe, with their cleavage.[1] Mr. Scrope, on the other hand, is inclined to attribute the foliation of the crystalline schists to 'the results of internal differential movements in the constituents of the subterranean mineral matter while exposed to enormous irregular pressures as well as variations of temperature, and under these influences changing at times from a solid to a fluid state and probably back again to crystalline solidity, through intervening phases of viscosity—movements and changes which must *of necessity* have frequently arranged and rearranged the component crystalline minerals, sometimes in irregular composition like that of granite, diorite, or trachyte, sometimes in laminar or schistose bands like those of gneiss, mica-schist, and other so-called metamorphic crystallines.'[2]

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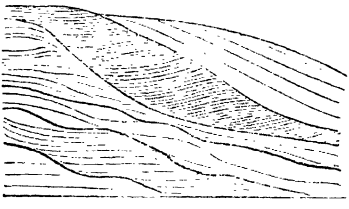
[1] Darwin, Volcanic Islands, pp. 69, 70.

[2] Norske Mag. Naturvidsk., vol. i. p. 71.

[3] Memoir read before the Geol. Soc. London, Jan. 31, 1855.

We have seen how much the original planes of stratification may be interfered with or even obliterated by concretionary action in deposits still retaining their fossils, as in the case of the magnesian limestone (see p. 40). Hence we must expect to be frequently baffled when we attempt to decide whether the foliation does or does not accord with that arrangement which gravitation, combined with current-action, imparted to a deposit from water. Moreover, when we look for stratification in crystalline rocks, we must be on our guard not to expect too much regularity. The occurrence of wedge-shaped masses, such as belong to coarse sand and pebbles,—diagonal lamination (p. 18),—ripple-marked,—unconformable stratification,—the fantastic folds produced by lateral pressure,—faults of various width,—intrusive dikes of trap,—organic bodies of diversified shapes,—and other causes of unevenness in the planes of deposition, both on the small and on the large scale, will interfere with parallelism. If complex and enigmatical appearances did not present themselves, it would be a serious objection to the metamorphic theory. Mr. Sorby has shown that the peculiar structure belonging to ripple-marked

Fig. 637.



Lamination of clay-stone, Montagne de Seguinat near Gavarnie, in the Pyrenees.

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[1] Quart. Geol. Journ., vol. xvii., 1861, p. 232.

[2] Scrope, 'Volcanoes,' 1872, preface, p. 18; and Geologist Mag. vol. i. p. 361.

CHAPTER XXXV.

ON THE DIFFERENT AGES OF THE METAMORPHIC ROCKS.

Difficulty of ascertaining the age of metamorphic strata—Metamorphic strata of Eocene date in the Alps of Switzerland and Savoy—Limestone and shale of Carrara—Metamorphic strata of older date than the Silurian and Cambrian rocks. Order of succession in metamorphic rocks. Uniformity of mineral character—Supposed Azoic Period—Connection between the absence of organic remains and the scarcity of calcareous matter in metamorphic rocks.

According to the theory adopted in the last chapter, the metamorphic strata have been deposited at one period, and have become crystalline at another. We can rarely hope to define with exactness the date of both these periods, the fossils having been destroyed by plutonic action, and the mineral characters being the same, whatever the age. Superposition itself is an ambiguous test, especially when we desire to determine the period of crystallisation. Suppose, for example, we are convinced that certain metamorphic strata in the Alps, which are covered by cretaceous beds, are altered lias; this lias may have assumed its crystalline texture in the cretaceous or in some tertiary period, the Eocene for example.

When discussing the ages of the plutonic rocks, we have seen that examples occur of various primary, secondary, and tertiary deposits converted into metamorphic strata, near their contact with granite. There can be no doubt in these cases that strata, once composed of mud, sand, and gravel, or of clay, marl, and shelly limestone, have for the distance of several yards, and in some instances several hundred feet, been turned into gneiss, mica-schist, hornblende-schist, chlorite-schist, quartz rock, statuary marble, and the rest. (See the two preceding chapters.) It may be easy to prove the identity of two different parts of the same stratum; one where the rock has been in contact with a volcanic or plutonic mass, and has been changed into marble or hornblende-schist, and another not far distant, where the same bed remains unaltered and fossiliferous; but when hydrothermal action, as described in the thirty-third chapter, has operated gradually on a more extensive scale, it may have finally destroyed all monuments of the date of its development throughout a whole mountain chain, and all the labour and skill of the most practised observers are required, and may sometimes be at fault. I shall mention one or two examples of alteration on a grand scale, in order to explain to the student the kind of reasoning by which we are led to infer that dense masses of fossiliferous strata have been converted into crystalline rocks.

Eocene strata rendered metamorphic in the Alps.—In the eastern part of the Alps, some of the Palæozoic strata, as well as the older Mesozoic formations, including the oolitic and cretaceous rocks, are distinctly recognisable. Tertiary deposits also appear in a less elevated position on the flanks of the Eastern Alps; but in the Central or Swiss Alps, the Palæozoic and older Mesozoic formations disappear, and the Cretaceous, Oolitic, Liassic, and at some points even the Eocene strata, graduate insensibly into metamorphic rocks, consisting of granular limestone, talc-schist, talcose-gneiss, micaceous schist, and other varieties.

As an illustration of the partial conversion into gneiss of portions of a highly inclined set of beds, I may cite Sir R. Murchison's memoir on the structure of the Alps. Slates provincially termed 'flysch' (see above, p. 262), overlying the nummulite limestone of Eocene date, and comprising some arenaceous and some calcareous layers, are seen to alternate several times with bands of granitoid rock, answering in character to gneiss. In this case heat, vapour, or water at a high temperature may have traversed the more permeable beds, and altered them so far as to admit of an internal movement and re-arrangement of the molecules, while the adjoining strata did not give passage to the same heated gases or water, or, if so, remained unchanged because they were composed of less fusible or decomposable materials. Whatever hypothesis we adopt, the phenomena establish beyond a doubt the possibility of the development of the metamorphic structure in a tertiary deposit in planes parallel to those of stratification. The strata appear clearly to have been affected, though in a less intense degree, by that same plutonic action which has entirely altered and rendered metamorphic so many of the subjacent formations; for in the Alps, this action has by no means been confined to the immediate vicinity of granite. Granite, indeed, and other plutonic rocks, rarely make their appearance at the surface, notwithstanding the deep ravines which lay open to view the internal structure of these mountains. That they exist below at no great depth we cannot doubt, for at some points, as in the Valorsine, near Mont Blanc, granite and granitic veins are observable, piercing through talcose gneiss, which passes insensibly upwards into secondary strata.

It is certainly in the Alps of Switzerland and Savoy, more than in any other district in Europe, that the geologist is prepared to meet with the signs of an intense development of plutonic action ; for here strata thousands of feet thick have been bent, folded, and overturned, and marine secondary formations of a comparatively modern date, such as the Oolitic and Cretaceous, have been upheaved to the height of 12,000, and some Eocene strata to elevations of 10,000 feet above the level of the sea ; and even deposits of the Miocene era have been raised 4,000 or 5,000 feet, so as to rival in height the loftiest mountains in Great Britain. In one of the sections described by M. Studer in the highest of the Bernese Alps, namely in the Roththal, a valley bordering the line of perpetual snow on the northern side of the Jungfrau, there occurs a mass of gneiss 1,000 feet thick, and 15,000 feet long, which I examined, not only resting upon, but also again covered by strata containing oolitic fossils. These anomalous appearances may partly be explained by supposing great solid wedges of intrusive gneiss to have been forced in laterally between strata to which I found them to be in many sections unconformable. The superposition also of the gneiss to the oolite may, in some cases, be due to a reversal of the original position of the beds in a region where the convulsions have been on so stupendous a scale.

Northern Apennines—Carrara.—The celebrated marble of Carrara, used in sculpture, was once regarded as a type of primitive limestone. It abounds in the mountains of Massa Carrara, or the 'Apuan Alps,' as they have been called, the highest peaks of which are nearly 6,000 feet high. Its great antiquity was inferred from its mineral texture, from the absence of fossils, and its passage downwards into talc-schist and garnetiferous mica-schist ; these rocks again graduating downwards into gneiss, which is penetrated, at Forno, by granite veins. But the researches of MM. Savi, Boué, Pareto, Guidoni, De la Beche, Hoffmann, and Pilla demonstrated that this marble, once supposed to be formed before the existence of organic beings, is, in fact, an altered limestone of the Oolitic period, and the underlying crystalline schists are secondary or Mesozoic sandstones and shales, modified by plutonic action. In order to establish these conclusions it was first pointed out, that the calcareous rocks bordering the Gulf of Spezzia, and abounding in Oolitic fossils, assume a texture like that of Carrara marble, in proportion as they are more and more invaded by certain trappean and plutonic rocks, such as diorite, serpentine, and granite, occurring in the same country.

It was then observed that, in places where the secondary formations are unaltered, the uppermost consist of common Apennine limestone with nodules of flint, below which are shales, and at the base of all, argillaceous and siliceous sandstones. In the limestone, fossils are frequent, but very rare in the underlying shale and sandstone. Then a gradation was traced laterally from these rocks into another and corresponding series, which is completely metamorphic; for at the top of this we find a white granular marble, wholly devoid of fossils, and almost without stratification, in which there are no nodules of flint, but in its place siliceous matter disseminated through the mass in the form of prisms of quartz. Below this, and in place of the shales, are talc-schists, jasper, and hornstone; and at the bottom, instead of the siliceous and argillaceous sandstones, are quartzite and gneiss.[1] Had these secondary strata of the Apennines undergone universally as great an amount of transmutation, it would have been impossible to form a conjecture respecting their true age; and then, according to the method of classification adopted by the earlier geologists, they would have ranked as primary rocks. In that case the date of their origin would have been thrown back to an era antecedent to the deposition of all fossiliferous strata, although in reality they were formed in the Oolitic period, and altered at some subsequent and perhaps much later epoch.

Metamorphic strata of older date than the Silurian and Cambrian Rocks.—It was remarked, fig. 626, p. 567, that as the hypogene rocks, both stratified and unstratified, crystallise originally at a certain depth beneath the surface, they must always, before they are upraised and exposed at the surface, be of considerable antiquity, relatively to a large portion of the fossiliferous and volcanic rocks. They may be forming at all periods; but before any of them can become visible, they must be raised above the level of the sea, and some of the rocks which previously concealed them must have been removed by denudation.

In Canada, as we have seen (p. 491), the Lower Laurentian gneiss, quartzite, and limestone may be regarded as metamorphic, because among other reasons organic remains (*Eozoon Canadense*) have been detected in a part of one of the calcareous masses. The Upper Laurentian or Labrador series lies unconformably upon the Lower, and differs from it chiefly in having as yet yielded no fossils. It consists of gneiss with Labrador-felspar and felstones, in all 10,000 feet thick, and both its composition and structure lead us to suppose that, like the Lower Laurentian, it was originally of sedimentary origin and owes its crystalline condition to metamorphic action. The remote date of the period when some of these old Laurentian strata of Canada were converted into gneiss, may be inferred from the fact that pebbles of that rock are found in the overlying Huronian formation, which is probably of Cambrian age (p. 489).

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[1] See notices of Savi, Hoffmann, and others, referred to by Boué, Bull. de la Soc. Géol. de France tom. v. p. 317; and tom. iii. p. 44; also Pilla, cited by Murchison, Quart. Geol. Journ., vol. v. p. 266.

The oldest stratified rock of Scotland is the hornblendic gneiss of Lewis, in the Hebrides, and that of the north-west coast of Ross-shire, represented at the base of the section given at fig. 82, p. 89. It is the same as that intersected by numerous granite veins, which forms the cliffs of Cape Wrath, in Sutherlandshire (see fig. 622, p. 560), and is conjectured to be of Laurentian age. Above it, as shown in the section (fig. 82, p. 89), lie unconformable beds of a reddish or purplish sandstone and conglomerate, nearly horizontal, and between 3,000 and 4,000 feet thick. In these ancient grits no fossils have been found, but they are supposed to be of Cambrian date, for Sir R. Murchison found Lower Silurian strata resting unconformably upon them. These strata consist of quartzite with annelid burrows already alluded to (p. 89), and limestone in which Mr. Charles Peach was the first to find in 1854 three or four species of *Orthoceras*, also the genera *Cyrtoceras* and *Lituites*, two species of *Murchisonia*, a *Pleurotomaria*, a species of *Maclurea*, one of *Euomphalus*, and an *Orthis*. Several of the species are believed by Mr. Salter to be identical with Lower Silurian fossils of Canada and the United States.

The discovery of the true age of these fossiliferous rocks was one of the most important steps made of late years in the progress of British Geology, for it led to the unexpected conclusion that all the Scotch crystalline strata to the eastward, once called primitive, which overlie the limestone and quartzite in question, are referable to some part of the Silurian series.

These Scotch metamorphic strata are of gneiss, mica-schist, and clay-slate of vast thickness, and having a strike from north-east to south-west almost at right angles to that of the older Laurentian gneiss before mentioned. The newer crystalline series, comprising the crystalline rocks of Aberdeenshire, Perthshire, and Forfarshire, were inferred by Sir R. Murchison to be altered Silurian strata, and his opinion has been since confirmed by the observations of three able geologists, Messrs. Ramsay, Harkness, and Geikie. The newest of the series is a clay-slate, on which, along the southern borders of the Grampians, the Lower Old Red, containing *Cephalaspis Lyelli*, *Pterygotus Anglicus*, and *Parka decipiens*, rests unconformably.

Order of succession in metamorphic rocks.—There is no universal and invariable order of superposition in metamorphic rocks, although a particular arrangement may prevail throughout countries of great extent, for the same reason that it is traceable in those sedimentary formations from which crystalline strata are derived. Thus, for example, we have seen that in the Apennines, near Carrara, the descending series, where it is metamorphic, consists of, 1st, saccharine marble; 2ndly, talcose-schist; and 3rdly, of quartz-rock and gneiss: where unaltered, of 1st, fossiliferous limestone; 2ndly, shale; and 3rdly, sandstone.

But if we investigate different mountain chains, we find gneiss, mica-schist, hornblende-schist, chlorite-schist, hypogene limestone, and other rocks, succeeding each other, and alternating with each other in every possible order. It is, indeed, more common to meet with some variety of clay-slate forming the uppermost member of a metamorphic series than any other rock; but this fact by no means implies, as some have imagined, that all clay-slates were formed at the close of an imaginary period, when the deposition of the crystalline strata gave way to that of ordinary sedimentary deposits. Such clay-slates, in fact, are variable in composition, and sometimes alternate with fossiliferous strata, so that they may be said to belong almost equally to the sedimentary and metamorphic order of rocks. It is probable that had they been subjected to more intense plutonic action, they would have been transformed into hornblende-schist, foliated chlorite-schist, scaly talcose-schist, mica-schist, or other more perfectly crystalline rocks, such as are usually associated with gneiss.

Uniformity of mineral character in Hypogene Rocks.—It is true, as Humboldt has happily remarked, that when we pass to another hemisphere, we see new forms of animals and plants, and even new constellations in the heavens; but in the rocks we still recognise our old acquaintances—the same granite, the same gneiss, the same micaceous schist, quartz-rock, and the rest. There is certainly a great and striking general resemblance in the principal kinds of hypogene rocks in all countries, however different their ages; but each of them, as we have seen, must be regarded as geological families of rocks, and not as definite mineral compounds. They are more uniform in aspect than sedimentary strata, because these last are often composed of fragments varying greatly in form, size, and colour, and contain fossils of different shapes and mineral composition, and acquire a variety of tints from the mixture of various kinds of sediment. The materials of such strata, if they underwent metamorphism, would be subject to chemical laws, simple and uniform in their action, the same in every climate, and wholly undisturbed by mechanical and organic causes. It would, however, be a great error to assume, as some have done, that the hypogene rocks, considered as aggregates of simple minerals, are really more homogeneous in their composition than the several members of the sedimentary series; for the proportional quantities of felspar, quartz, mica, hornblende, and other minerals, vary considerably in hypogene rocks bearing the same name.

Supposed Azoic Period.—The total absence of any trace of fossils has inclined many geologists to attribute the origin of the most ancient strata to an azoic period or one antecedent to the existence of organic beings. Admitting, they say, the obliteration, in some cases, of fossils by plutonic action, we might still expect that traces of them would oftener be found in certain ancient systems of slate which can scarcely be said to have assumed a crystalline structure. But in urging this argument, it seems to have been forgotten that there are stratified formations of enormous thickness, and of various ages, some of them even of Tertiary date, which we know were formed after the earth had become the abode of living creatures, and are, nevertheless, in some districts, entirely destitute of all vestiges of organic bodies. In some, the traces of fossils may have been effaced by water and acids, at many successive periods; indeed, the removal of the calcareous matter of fossil shells is proved by the fact of such organic remains being often replaced by silex or other minerals, and sometimes by the space once occupied by the fossil being left empty or only marked by a faint impression.

In support of this view the fact must be remembered that limestones and clays of Lias age and crowded with fossils, especially the *Gryphæa arcuata*, are found in the Hebrides graduating into rocks which are so altered that not the faintest traces of the organic structures can be detected in them. And again, while a bed of Metamorphic Lower Silurian limestone in Durness has yielded (see above, p. 602) to the patient search of Mr. Charles Peach at one favourable locality, a number of beautiful fossils, exposed upon the weathered surfaces of the rock, yet the most careful examination of similar beds of limestone upon the same geological horizon which has been made by different observers at many other points has not in any single instance been rewarded by similar discoveries.

Those who believed the hypogene rocks to have originated antecedently to the creation of organic beings, imputed the absence of lime so remarkable in metamorphic strata to the non-existence of those mollusca and zoophytes by which shells and corals are secreted ; but when we ascribe the crystalline formations to plutonic action, it is natural to enquire whether this action itself may not tend to expel carbonic acid and lime from the materials which it reduces to fusion or semi-fusion. Not only carbonate of lime, but also free carbonic acid gas is given off plentifully from the soil and crevices of rocks in regions of active and spent volcanos, as near Naples and in Auvergne. By this process, fossil shells or corals may often lose their carbonic acid, and the residual lime may enter into the composition of augite, hornblende, garnet, and other hypogene minerals. Although we cannot descend into the subterranean regions where volcanic heat is developed, we can observe in regions of extinct volcanos, such as Auvergne and Tuscany, hundreds of springs, both cold and thermal, flowing out from granite and other rocks, and having their waters plentifully charged with carbonate of lime.

If all the calcareous matter transferred in the course of ages by these and thousands of other springs from the lower part of the earth's crust to the atmosphere, could be presented to us in a solid form, we should find that its volume was comparable to that of many a chain of hills. Calcareous matter is poured into lakes and the ocean by a thousand springs and rivers ; so that part of almost every new calcareous rock chemically precipitated, and of many reefs of shelly and coralline stone, must be derived from mineral matter subtracted by plutonic agency, and driven up by gas and steam from fused and heated rocks in the bowels of the earth.

The scarcity of limestone in many extensive regions of metamorphic rocks, as in the Eastern and Southern Grampians of Scotland, may have been the result of some action of this kind ; and if the limestones of the Lower Laurentian in Canada afford a remarkable exception to the general rule, we must not forget that it is precisely in this most ancient formation that the *Eozoon Canadense* has been found. The fact that some distinct bands of limestone from 700 to 1,500 feet thick occur here, may be connected with the escape from destruction of some few traces of organic life, even in a rock in which metamorphic action has gone so far as to produce serpentine, augite, and other minerals found largely intermixed with the carbonate of lime.

CHAPTER XXXVI.

MINERAL VEINS.

Different kinds of mineral veins—Ordinary metalliferous veins or lodes—Their frequent coincidence with faults—Proofs that they originated in fissures in solid rock—Veins shifting other veins—Polishing of their walls or 'slicken-sides'—Shells and pebbles in lodes—Evidence of the successive enlargement and reopening of veins—Examples in Cornwall and in Auvergne—Dimensions of veins—Why some alternately swell out and contract—Filling of lodes by sublimation from below—Supposed relative age of the precious metals—Copper and lead veins in Ireland older than Cornish tin—Lead vein in lias, Glamorganshire—Gold in Russia, California, and Australia—Origin of mineral veins.

The manner in which metallic substances are distributed through the earth's crust, and more especially the phenomena of those more or less connected masses of ore called mineral veins, from which the larger part of the precious and other metals used by man is obtained, are subjects of the highest practical importance to the miner, and of no less theoretical interest to the geologist.

On different kinds of mineral veins.—The mineral veins with which we are most familiarly acquainted, are those of quartz and carbonate of lime, which are often observed to form lenticular masses of limited extent traversing both hypogene strata and fossiliferous rocks. Such veins appear to have once been chinks or small cavities, caused, like cracks in clay, by the shrinking of the mass, during desiccation, or in passing from a higher to a lower temperature. Siliceous, calcareous, and occasionally metallic matters have sometimes found their way simultaneously into such empty spaces, by infiltration from the surrounding rocks. Mixed with hot water and steam, metallic ores may have permeated the mass until they reached those receptacles formed by shrinkage, and thus gave rise to that irregular assemblage of veins, called by the Germans a 'stockwerk,' in allusion to the different floors on which the mining operations are in such cases carried on.

The more ordinary or regular veins are usually worked in vertical shafts, and have evidently been fissures produced by mechanical violence. They traverse all kinds of rocks, both hypogene and fossiliferous, and extend downwards to indefinite or unknown depths. We may assume that they correspond with such rents as we see caused from time to time by the shock of an earthquake. Metalliferous veins, referable to such agency, are occasionally a few inches wide, but more commonly 3 or 4 feet. They hold their course continuously in a certain prevailing direction for miles or leagues, passing through rocks varying in mineral composition.

That metalliferous veins were fissures.—As some intelligent miners, after an attentive study of metalliferous veins, have been unable to reconcile many of their characteristics with the hypothesis of fissures, I shall begin by stating the evidence in its favour. The most striking fact perhaps which can be adduced in its support is, the coincidence of a considerable proportion of mineral veins with *faults*, or those dislocations of rocks which are indisputably due to mechanical force, as above explained (p. 64). There are even proofs in almost every mining district of a succession of faults, by which the opposite walls of rents, now the receptacles of metallic substances, have suffered displacement. Thus, for example, suppose *a a*, fig. 638, p. 609, to be a tin lode in Cornwall, the term *lode* being applied to veins containing metallic ores. This lode, running east and west, is a yard wide, and is shifted by a copper lode (*b b*), of similar width. The first fissure (*a a*) has been filled with various materials, partly of chemical origin, such as quartz, fluor-spar, tinstone, copper-glance, arsenical pyrites, native bismuth, and nickeliferous pyrites, and partly of mechanical origin, comprising clay and angular fragments or detritus of the intersected rocks. The successive deposits of spars and ores are, in some places, parallel to the vertical sides or walls of the vein, being divided from each other by alternating layers of clay, or other earthy matter. Occasionally, however, the metallic ores are disseminated in detached masses among the sparry minerals or vein-stones.

It is clear that, after the gradual introduction of the tinstone and other substances, the second rent (*b b*) was produced by another fracture accompanied by a displacement of the rocks along the plane of *b b*. This new opening was then filled with minerals, some of them resembling those in *a a*, as fluor-spar and quartz; others different, the copper ore being plentiful, and the tin ore wanting or very scarce. We must next suppose a third movement to occur, breaking asunder all the rocks along the line *c c*, fig. 639; the fissure, in this instance, being only 6 inches wide, and simply filled with clay, derived, probably, from the friction of the walls of the rent, or partly, perhaps, washed in from above. This new movement has displaced the rock in such a manner as to interrupt the continuity of the copper vein (*b b*), and, at the same time, to shift or heave laterally in the same direction a portion of the tin vein which had not previously been broken.

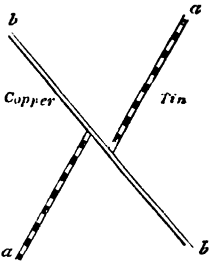


Fig. 639.

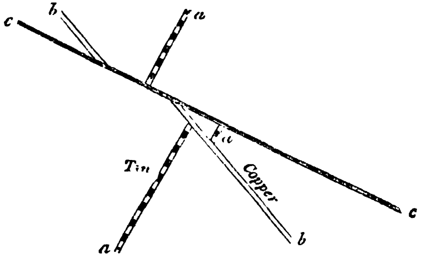
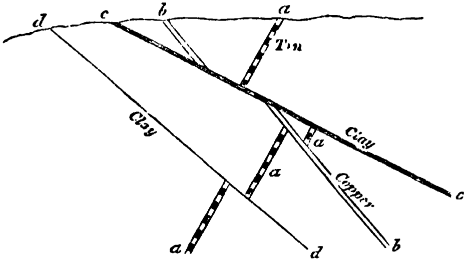


Fig. 640.



Vertical sections of the mine of Huel Peever, Redruth, Cornwall.

Again, in fig. 640 we see evidence of a fourth fissure (*d d*), also filled with clay, which has cut through the tin vein (*a a*), and has lifted it slightly upwards towards the south. The various changes here represented are not ideal, but are exhibited in a section obtained in working an old Cornish mine, long since abandoned, in the parish of Redruth, called Huel Peever, and described both by Mr. Williams and Mr. Carne.[1] The principal movement here referred to, or that of *c c*, fig. 640, extends through a space of no less than 84 feet; but in this, as in the case of the other three, it will be seen that the outline of the country above, *d*, *c*, *b*, *a*, &c., or the geographical features of Cornwall, are not affected by any of the dislocations, a powerful denuding force having clearly been exerted subsequently to all the faults. (See above, p. 70.) It is commonly said in Cornwall, that there are eight distinct systems of veins, which can in like manner be referred to as many successive movements or fractures; and the German miners of the Hartz Mountains speak also of eight systems of veins, referable to as many periods.

Besides the proofs of mechanical action already explained, the opposite walls of veins are often beautifully polished, as if glazed, and are not unfrequently striated or scored with parallel furrows and ridges, such as would be produced by the continued rubbing together of surfaces of unequal hardness. These smoothed surfaces resemble the rocky floor over which a glacier has passed (see fig., p. 145). They are common even in cases where there has been no shift, and occur equally in non-metalliferous fissures. They are called by miners 'slicken-sides,' from the German *schlichten*, to plane, and *seite*, side. It is supposed that the lines of the striæ indicate the direction in which the rocks were moved.

In some of the veins in the mountain limestone of Derbyshire, containing lead, the vein-stuff, which is nearly compact, is occasionally traversed by what may be called a vertical crack passing down the middle of the vein. The two faces in contact are slicken-sides, well polished and fluted, and sometimes covered by a thin coating of lead-ore. When one side of the vein-stuff is removed, the other side cracks, especially if small holes be made in it, and fragments fly off with loud explosions, and continue to do so for some days. The miner, availing himself of this circumstance, makes with his pick small holes about 6 inches apart and 4 inches deep, and on his return in a few hours finds every part ready broken to his hand.[2]

That a great many veins communicated originally with the surface of the country above, or with the bed of the sea, is proved by the occurrence in them of well-rounded pebbles, agreeing with those in superficial alluviums, as in Auvergne and Saxony. Marine fossil shells also have been found at great depths, having probably been engulphed during submarine earthquakes. Thus, a gryphæa is stated by M. Virlet to have been met with in a lead-mine near Sémur, in France, and a madrepore in a compact vein of cinnabar in Hungary.[1] Mr. C. Moore has described lead-veins traversing the carboniferous limestone of the south-west of England, which at the time they were filled must have certainly been in communication with the Liassic sea, for in them have been found at great depths characteristic Lias fossils.[2] In Bohemia, similar pebbles have been met with at the depth of 180 fathoms, and in Cornwall, Mr. Carne mentions true pebbles of quartz and slate in a tin lode of the Relistran Mine, at the depth of 600 feet below the surface. They were cemented by tinstone and copper pyrites, and were traced over a space more than 12 feet long and as many wide.[3] When different sets or systems of veins occur in the same country, those which are supposed to be of contemporaneous origin, and which are filled with the same kind of metals, often maintain a general parallelism of direction. Thus, for example, both the tin and copper veins in Cornwall run nearly east and west, while the lead-veins run north and south; but there is no general law of direction common to different mining districts. The parallelism of the veins is another reason for regarding them as ordinary fissures, for we observe that faults and trap dikes, admitted by all to be masses of melted matter which have filled rents, are often parallel.

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[1] Geol. Trans., vol. iv. p. 139; Trans. Royal Geol. Soc., Cornwall, vol. ii. p. 90.

[2] Conyb. and Phil. Geol. p. 401; and Farey's Derbyshire, p 243

Fracture, reopening, and successive formation of veins.—Assuming, then, that veins are simply fissures in which chemical and mechanical deposits have accumulated, we may next consider the proofs of their having been filled gradually and often during successive enlargements.

Werner observed, in a vein near Gersdorff, in Saxony, no less than thirteen beds of different minerals, arranged with the utmost regularity on each side of the central layer. This layer was formed of two plates of calcareous spar, which had evidently lined the opposite walls of a vertical cavity. The thirteen beds followed each other in corresponding order, consisting of fluor-spar, heavy spar, galena, &c. In these cases the central mass has been last formed, and the two plates which coat the walls of the rent on each side are the oldest of all. If they consist of crystalline precipitates, they may be explained by supposing the fissure to have remained unaltered in its dimensions, while a series of changes occurred in the nature of the solutions which rose up from below: but such a mode of deposition, in the case of many successive and parallel layers, appears to be exceptional.

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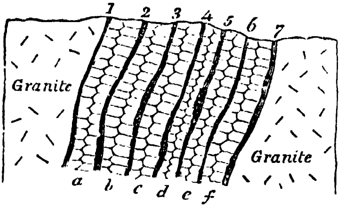
[1] Fournet, Études sur les Dépôts Métallifères.

[2] Quart. Geol. Journ., vol. xxiii. (1867) p. 449.

[3] Carne, Trans. of Geol. Soc. Cornwall, vol. iii. p. 238.

If a veinstone consist of crystalline matter, the points of the crystals are always turned inwards, or towards the centre of the vein; in other words, they point in the direction where there was space for the development of the crystals. Thus each new layer receives the impression of the crystals of the preceding layer, and imprints its crystals on the one which follows, until at length the whole of the vein is filled: the two layers which meet dovetail the points of their crystals the one into the other. But in Cornwall, some lodes occur where the vertical plates, or *combs*, as they are there called, exhibit crystals so dovetailed as to prove that the same fissure has been often enlarged. Sir H. De la Beche gives the following curious and instructive example (fig. 641), from a copper-mine in granite, near Redruth.[1] Each of the plates or combs (*a*, *b*, *c*, *d*, *e*, *f*) is double, having the points of their crystals turned inwards along the axis of the comb. The sides or walls (2, 3, 4, 5, and 6) are parted by a thin covering of ochreous clay, so that each comb is readily separable from another by a moderate blow of the hammer. The breadth of each represents the whole width of the fissure at six successive periods, and the outer walls of the vein, where the first narrow rent was formed, consisted of the granitic surfaces 1 and 7.

Fig. 641.



Copper lode, near Redruth, enlarged at six successive periods.

A somewhat analogous interpretation is applicable to many other cases, where clay, sand, or angular detritus alternate with ores and veinstones. Thus, we may imagine the sides of a fissure to be encrusted with siliceous matter as Von Buch observed, in Lancerote, the walls of a volcanic crater formed in 1731 to be traversed by an open rent in which hot vapours had deposited hydrous silica, the incrustation nearly extending to the middle.[2] Such a vein may then be filled with clay or sand, and afterwards reopened, the new rent dividing the argillaceous deposit, and allowing a quantity of rubbish to fall down. Various ores and spars may then be precipitated from aqueous solutions among the interstices of this heterogeneous mass.

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[1] Geol. Rep. on Cornwall, p. 340.

[2] Principles, Index 'Lancerote.'

That such changes have repeatedly occurred is demonstrated by occasional cross-veins, implying the oblique fracture of previously formed chemical and mechanical deposits. Thus, for example, M. Fournet, in his description of some mines in Auvergne worked under his superintendence, observes that the granite of that country was first penetrated by veins of massive granite, and then dislocated, so that open rents crossed both the granite and the granitic veins. Into such openings, quartz, accompanied by iron pyrites and arsenical pyrites, was introduced. Another convulsion then burst open the rocks along the old line of fracture, and the first set of deposits was cracked and often shattered, so that the new rent was filled, not only with angular fragments of the adjoining rocks, but with pieces of the older veinstones. Polished and striated surfaces on the sides or in the contents of the vein also attest the reality of these movements. A new period of repose then ensued, during which various sulphides were introduced, together with quartz of the variety known as horn-stone, by which angular fragments of the older quartz before mentioned were cemented into a breccia. This period was followed by other dilatations of the same veins, and the introduction of other sets of mineral deposits, as well as of pebbles of the basaltic lavas of Auvergne, derived from superficial alluviums, probably of Miocene or even older Pliocene date. Such repeated enlargement and reopening of veins might have been anticipated, if we adopt the theory of fissures, and reflect how few of them have ever been sealed up entirely, and that a country with fissures only partially filled must naturally offer much feebler resistance along the old lines of fracture than anywhere else.

Cause of alternate contraction and swelling of veins.—A large proportion of metalliferous veins have their opposite walls nearly parallel, and sometimes over a wide extent of country. There is a fine example of this in the celebrated vein of Andreasburg in the Hartz, which has been worked for a depth of 500 yards perpendicularly, and 200 horizontally, retaining almost everywhere a width of 3 feet. But many lodes in Cornwall and elsewhere are extremely variable in size, being 1 or 2 inches in one part, and then 8 or 10 feet in another, at the distance of a few fathoms, and then again narrowing as before. Such alternate swelling and contraction is so often characteristic as to require explanation. The walls of fissures in general, observes Sir

H. De la Beche, are rarely perfect planes throughout their entire course, nor could we well expect them to be so, since they commonly pass through rocks of unequal hardness and different mineral composition. If, therefore, the opposite sides of such irregular fissures slide upon each other, that is to say, if there be a fault, as in the case of so many mineral veins, the parallelism of the opposite walls is at once entirely destroyed, as will be readily seen by studying the annexed diagrams.

Let *a b*, fig. 642, be a line of fracture traversing a rock, and let *a b*, fig. 643, represent the same line. Now, if we cut in two a piece of paper representing this line, and then move the lower portion of this cut paper sideways from *a* to *a′*, taking care that the two pieces of paper still touch each other at the points 1, 2, 3, 4, 5, we obtain an irregular aperture at *c*, and isolated cavities *d d d*, and when we compare such figures with nature we find that, with certain modifications, they represent the interior of faults and mineral veins. If, instead of sliding the cut paper to the right hand, we move the lower part towards the left, about the same distance that it was previously slid to the right, we obtain considerable variation in the cavities so produced, two long irregular open spaces, *f f*, fig. 644, being then formed. This will serve to show to what slight circumstances considerable variations in the character of the openings between unevenly fractured surfaces may be due, such surfaces being moved upon each other, so as to have numerous points of contact.

Fig. 642.

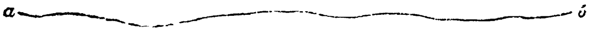


Fig. 643.

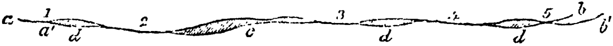


Fig. 644.

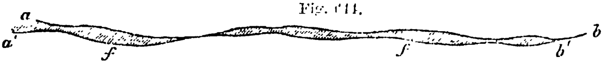
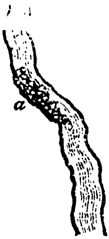


Fig. 645.



Most lodes are perpendicular to the horizon, or nearly so; but some of them have a considerable inclination or 'hade,' as it is termed, the angles of dip being very various. The course of a vein is frequently very straight; but if tortuous, it is found to be choked up with clay, stones, and pebbles, at points where it departs most widely from verticality. Hence at places, such as *a*, fig. 645, the miner complains that the ores are 'nipped,' or greatly reduced in quantity, the space for their free deposition having been interfered with in consequence of the preoccupancy of the lode by earthy materials. When lodes are many fathoms wide, they are usually filled for the most part with earthy matter, and fragments of rock, through which the ores are disseminated. The metallic substances frequently coat or encircle detached pieces of rock, which our miners call 'horses' or 'riders.' That we should find some mineral veins which split into branches is also natural, for we observe the same in regard to open fissures.

Chemical deposits in veins.—If we now turn from the mechanical to the chemical agencies which have been instrumental in the production of mineral veins, it may be remarked that those parts of fissures which were choked up with the ruins of fractured rocks must always have been filled with water ; and almost every vein has probably been the channel by which hot springs, so common in countries of volcanos and earthquakes, have made their way to the surface. For we know that the rents in which ores abound extend downwards to vast depths, where the temperature of the interior of the earth is more elevated. We also know that mineral veins are most metalliferous near the contact of plutonic and stratified formations, especially where the former send veins into the latter, a circumstance which indicates an original proximity of veins at their inferior extremity to igneous and heated rocks. It is moreover acknowledged that even those mineral and thermal springs which, in the present state of the globe, are far from volcanos, are nevertheless observed to burst out along great lines of upheaval and dislocation of rocks.[1] It is also ascertained that among the substances with which hot springs are impregnated, such as are volatile also occur in the gaseous emanations of volcanos. The whole of these are also among the constituents of the minerals most usually found in veins, such as quartz, calc-spar, fluor-spar, the metallic sulphides, heavy-spar, brown-spar, and the oxides of iron. I may add that, if veins have been filled with gaseous emanations from masses of melted matter, slowly cooling in the subterranean regions, the contraction of such masses as they pass from a plastic to a solid state would, according to the experiments of Deville on granite (a rock which may be taken as a standard), produce a reduction in volume amounting to 10 per cent. The slow crystallisation, therefore, of such plutonic rocks supplies us with a force not only capable of rending open the incumbent rocks by causing a failure of support, but also of giving rise to faults whenever one portion of the earth's crust subsides slowly while another contiguous to it happens to rest on a different foundation, so as to remain unmoved.

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[1] See Dr. Daubeny's 'Volcanos.'

Although we are led to infer, from the foregoing reasoning, that there has often been an intimate connection between metalliferous veins and hot springs holding mineral matter in solution, yet we must not on that account expect that the contents of hot springs and mineral veins would be identical. On the contrary, M. E. de Beaumont has judiciously observed that we ought to find in veins those substances which, being least soluble, are not discharged by hot springs,—or that class of simple and compound bodies which the thermal waters ascending from below would first precipitate on the walls of a fissure, as soon as their temperature began slightly to diminish. The higher they mount towards the surface, the more will they cool till they acquire the average temperature of springs, being in that case chiefly charged with the most soluble substances, such as the alkalis, soda and potash. These are seldom met with in veins, although they enter so largely into the composition of granitic rocks.[1]

To a certain extent, therefore, the arrangement and distribution of metallic matter in veins may be referred to ordinary chemical action, or to those variations in temperature which waters holding the ores in solution must undergo as they rise upwards from great depths in the earth. But there are other phenomena which do not admit of the same simple explanation. Thus, for example, in Derbyshire, veins containing ores of lead, zinc, and copper, but chiefly lead, traverse alternate beds of limestone and basalt. The ore is plentiful where the walls of the rent consist of limestone, but is reduced to a mere string when they are formed of basalt, or 'toad-stone,' as it is called provincially. Not that the original fissure is narrower where the basalt occurs, but because more of the space is there filled with veinstones, and the waters at such points have not parted so freely with their metallic contents.

'Lodes in Cornwall,' says Mr. Robert W. Fox, 'are very much influenced in their metallic riches by the nature of the rock which they traverse, and they often change in this respect very suddenly, in passing from one rock to another. Thus many lodes which yield abundance of ore in granite, are unproductive in clay-slate, or killas, and *vice versâ*.'

Supposed relative age of the different metals.—After duly reflecting on the facts above described, we cannot doubt that mineral veins, like eruptions of granite or trap, are referable to many distinct periods of the earth's history, although it may be more difficult to determine the precise age of veins; because they have often remained open for ages, and because, as we have seen, the same fissure, after having been once filled, has frequently been reopened or enlarged. But besides this diversity of age, it has been supposed by some geologists that certain metals have been produced exclusively in earlier, others in more modern times,—that tin, for example, is of higher antiquity than copper, copper than lead or silver, and all of them more ancient than gold. I shall first point out that the facts once relied upon in support of some of these views are contradicted by later experience, and then consider how far any chronological order of arrangement can be recognised in the position of the precious and other metals in the earth's crust.

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[1] Bulletin, iv. p. 1278.

In the first place, it is not true that veins in which tin abounds are the oldest lodes worked in Great Britain. The Government survey of Ireland has demonstrated that in Wexford, veins of copper and lead (the latter as usual being argentiferous) are much older than the tin of Cornwall. In each of the two countries a very similar series of geological changes has occurred at two distinct epochs,—in Wexford, before the Devonian strata were deposited; in Cornwall, after the carboniferous epoch. To begin with the Irish mining district: We have granite in Wexford, traversed by granite veins, which veins also intrude themselves into the Silurian strata, the same Silurian rocks as well as the veins having been denuded before the Devonian beds were superimposed. Next we find, in the same county, that elvans, or straight dikes of porphyritic felsite, have cut through the granite and the veins before mentioned, but have not penetrated the Devonian rocks. Subsequently to these elvans, veins of copper and lead were produced, being of a date certainly posterior to the Silurian, and anterior to the Devonian; for they do not enter the latter, and what is still more decisive, streaks or layers of derivative copper have been found near Wexford in the Devonian, not far from points where mines of copper are worked in the Silurian strata.

Although the precise age of such copper lodes cannot be defined, we may safely affirm that they were either filled at the close of the Silurian or commencement of the Devonian period. Besides copper, lead, and silver, there is some gold in these ancient or primary metalliferous veins. A few fragments also of tin found in Wicklow in the drift are supposed to have been derived from veins of the same age.[1]

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[1] Sir H. De la Beche, MS. Notes on Irish Survey.

Next, if we turn to Cornwall, we find there also the monuments of a very analogous sequence of events. First the granite was formed; then, about the same period, veins of fine-grained granite, often tortuous (see fig. 622, p. 560), penetrating both the outer crust of granite and the adjoining Paleozoic fossiliferous rocks, including the coal-measures; thirdly, elvans, holding their course straight through granite, granitic veins, and fossiliferous slates; fourthly, veins of tin also containing copper, the first of those eight systems of fissures of different ages already alluded to, p. 610. Here, then, the tin lodes are newer than the elvans. It has indeed been stated by some Cornish miners that the elvans are in some instances posterior to the oldest tin-bearing lodes, but the observations of Sir H. De la Beche during the survey led him to an opposite conclusion, and he has shown how the cases referred to in corroboration can be otherwise interpreted.[1] We may, therefore, assert that the most ancient Cornish lodes are younger than the coal-measures of that part of England, and it follows that they are of a much later date than the Irish copper and lead of Wexford and some adjoining counties. How much later, it is not so easy to declare, although probably they are not newer than the beginning of the Permian period, as no tin lodes have been discovered in any red sandstone which overlies the coal in the south-west of England.

There are lead veins in Glamorganshire which enter the lias, and others near Frome, in Somersetshire, which have been traced into the Inferior Oolite. In Bohemia, the rich veins of silver of Joachimsthal cut through basalt containing olivine, which overlies tertiary lignite, in which are leaves of dicotyledonous trees. This silver, therefore, is decidedly a tertiary formation. In regard to the age of the gold of the Ural Mountains, in Russia, which, like that of California, is obtained chiefly from auriferous alluvium, it occurs in veins of quartz in the schistose and granitic rocks of that chain, and is supposed by Sir R. Murchison, MM. De Verneuil and Keyserling to be newer than the hornblendic granite of the Ural—perhaps of tertiary date. They observe, that no gold has yet been found in the Permian conglomerates which lie at the base of the Ural Mountains, although large quantities of iron and copper detritus are mixed with the pebbles of those Permian strata. Hence it seems that the Uralian quartz veins, containing gold and platinum, were not formed, or certainly not exposed to aqueous denudation, during the Permian era.

In the auriferous alluvium of Russia, California, and Australia, the bones of extinct land-quadrupeds have been met with, those of the mammoth being common in the gravel at the foot of the Ural Mountains, while in Australia they consist of huge marsupials, some of them of the size of the rhinoceros and allied to the living wombat. They belong to the genera Diprotodon and Nototherium of Professor Owen. The gold of Northern Chili is associated in the mines of Los Hornos with copper pyrites, in veins traversing the cretaceo-jurassic formations, so called because its fossils have the character partly of the cretaceous and partly of the jurassic fauna of Europe.[1] The gold found in the United States, in the mountainous parts of Virginia, North and South Carolina, and Georgia, occurs in metamorphic Silurian strata, as well as in auriferous gravel derived from the same. In Queensland, according to the researches of Mr. Daintree, the auriferous lodes are entirely confined to those districts which are traversed by a series of trap-rocks of peculiar character.[2]

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[1] Report on Geology of Cornwall, p. 310.

Gold has now been detected in almost every kind of rock, in slate, quartzite, sandstone, limestone, granite, and serpentine, both in veins and in the rocks themselves at short distances from the veins. In Australia it has been worked successfully not only in alluvium, but in veinstones in the native rock, generally consisting of Silurian shales and slates. It has been traced on that continent over more than nine degrees of latitude (between the parallels of 30° and 39° S.), and over twelve of longitude, and yielded in 1853 an annual supply equal, if not superior, to that of California ; nor is there any apparent prospect of this supply diminishing, still less of the exhaustion of the gold-fields.

Origin of gold in California and South America.—In 1864 Professor Whitney[3] showed that the detrital gold deposits worked in California were of fluviatile origin and of two distinct ages : the more ancient or Pliocene had been protected by a cover of hard lava poured out over it from the volcanos of the higher part of the Sierra ; whilst the later or Post-tertiary auriferous gravels, formed since the period of greatest volcanic activity above alluded to, contained remains of the mastodon and elephant, and belong to the epoch of man. He also announced that some of the gold veins themselves were probably of cretaceous age, as had been shown to be the case in South America by Mr. David Forbes.[4] The last-mentioned mineralogist had already in 1861 advanced the opinion that the gold veins in South America and many other countries were of two distinct ages, and connected with the outbursts of respectively Granitic or Dioritic rocks, the former or older being not later than the carboniferous, and the latter as recent as the cretaceous period.

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[1] Darwin's S. America, p. 209, &c.

[2] Quart. Geol. Journ., vol. xxviii. 1872, p. 291.

[3] Amer. Journ. Scien., Sep. 1864.

[4] Quart. Journ. Geol. Soc., vol. xvii. 1861.

Mr. J. Arthur Phillips stated his belief in 1868[1] that the formation of recent metalliferous veins is now going on in various parts of the Pacific Coast. Thus, for example, there are fissures at the foot of the eastern declivity of the Sierra Nevada in the State of that name, from which boiling water and steam escape, forming siliceous incrustations on the sides of the fissures. In one case where the fissure is partially filled up with silica enclosing iron and copper pyrites, gold is said to have been found in the veinstone. Mr. Belt, however, who has lately made a special study of auriferous quartz veins in Nicaragua, is of opinion that although since the lodes were first filled they have been subjected to various chemical and hydrothermal agencies, the veins themselves have been originally igneous injections similar to the dikes and veins of granite.

Mr. Belt has also suggested geological reasons for the richness of ore near the surface of many gold fields. One thousand ounces of gold were obtained from a small patch of ore near the surface of the Consuelo lode in Nicaragua; and at Santo Domingo and elsewhere very rich ore was discovered within a few fathoms of the surface. When, however, these deposits were followed downwards, they invariably got poorer, and at one hundred feet from the surface no very rich ore has been met with. Below that, when the works are prosecuted still deeper there does not appear to be any further progressive deterioration in the value of the ore. The cause, says Mr. Belt, of these rich deposits near the surface does not appear to him to be that the lodes originally, before they were exposed to denudation, contained more gold in their upper portions than below, but to be the effect of the gradual denudation and wearing away of the surface, causing an accumulation of the loose gold in the upper parts of the lodes, derived from parts that originally stood higher, and have now been worn away by the action of the elements. This accumulation of loose gold near the surface of auriferous veins, set at liberty from its matrix by the decomposition of the ore, and concentrated by degradation, is probably the reason of the great richness of many of what are called the caps of quartz veins, that is, the parts next the existing surface, and has also perhaps originated the belief that auriferous veins deteriorate in value with depth.[2]

It has been remarked by M. De Beaumont, that lead and some other metals are found in dikes of basalt as well as in mineral veins connected with trap-rock, whereas tin is met with in granite and in veins associated with the plutonic series. If this rule hold true generally, the geological position of tin accessible to the miner will belong, for the most part, to rocks older than those bearing lead. The tin veins will be of higher relative antiquity for the same reason that the 'underlying' igneous formations or granites which are visible to man are older, on the whole, than the overlying or trappean formations. Mr. David Forbes[1] has also found in South America and elsewhere, that not only are metallic lodes intimately associated with the appearance of eruptive rocks in their vicinity, but also that their metallic contents are strongly influenced by the nature of the rock so intruded.

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[1] Proc. Royal Soc., 1868, p. 294.

[2] Belt, Naturalist in Nicaragua, 1874, p. 90.

If different sets of fissures, originating simultaneously at different levels in the earth's crust, and communicating, some of them with volcanic, others with heated plutonic masses, be filled with different metals, it will follow that those formed farthest from the surface will usually require the longest time before they can be exposed superficially. In order to bring them into view, or within reach of the miner, a greater amount of upheaval and denudation must take place in proportion as they have lain deeper when first formed and fitted. A considerable series of geological revolutions must intervene before any part of the fissure, which has been for ages in the proximity of the plutonic rocks, so as to receive the gases discharged from it when it was cooling, can emerge into the atmosphere. But I need not enlarge on this subject, as the reader will remember what was said in the 30th, 32nd, and 35th chapters, on the chronology of the volcanic and hypogene formations.

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[1] Mineralogy of South America, Phil. Mag., vol. xxix.

TABLE OF BRITISH FOSSILS.

THE following tables, which have been drawn up by Mr. Etheridge, refer, as will be seen by the title, exclusively to British fossils, and this will explain the absence of that portion of the Palæozoic series which is alluded to in Chapter XXVII. under the title of Laurentian, and in which the Eozoon found in Canada is at present the only known organism, and one not yet found in Britain.

The rise, culmination, and decrease of each Order or Family are shown by the gradual swelling out and thinning off of the black lines, while the survival of certain Orders or Families up to the present day is indicated by the reappearance of the black line in the Recent column, even when a gap in the British strata (as for example in the Miocene column) makes it appear as if such forms had died out. This method of indicating by black lines the rise and development of a fossil form was, I believe, first introduced by Bronn, adopted by Louis Agassiz, and afterwards constantly used by Edward Forbes in his geological lectures.

The table shows the range of all the chief Classes, Orders, and Families. The enumeration of Genera would occupy far too much space, although the information would have been extremely valuable.

TABLE OF BRITISH FOSSILS

ILLUSTRATIVE OF THE SUCCESSIVE APPEARANCE AND DEVELOPMENT IN TIME OF THE CHIEF ORDERS, CLASSES, OR FAMILIES OF ANIMALS AND PLANTS.

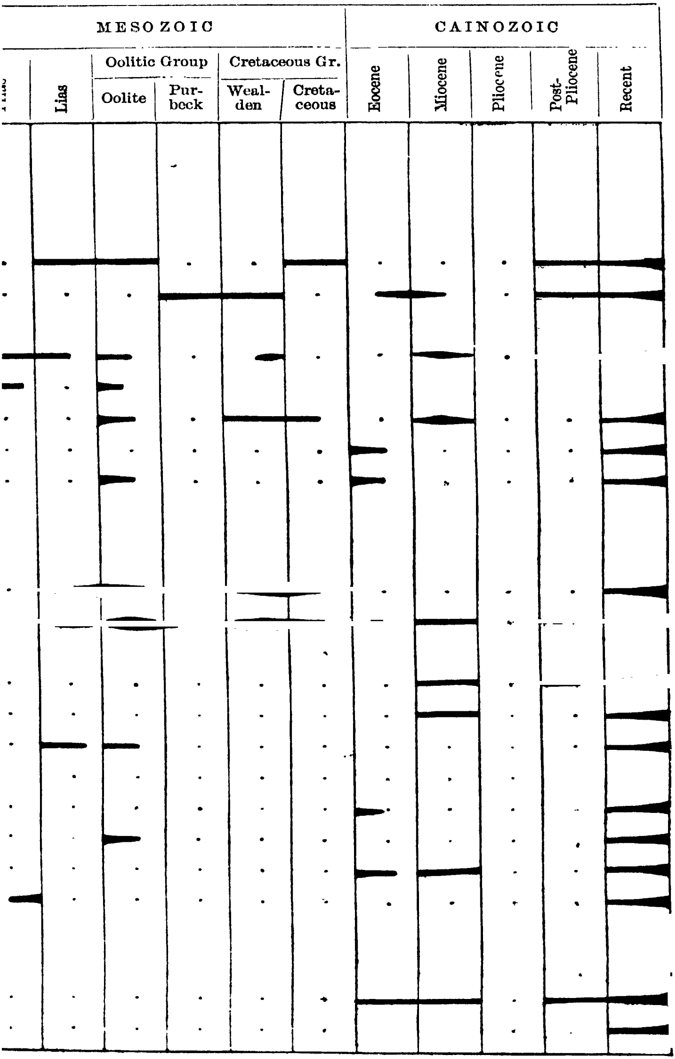
N.B.—The column headed 'Recent' indicates the survival of certain classes and families (the Marsupialia and Palms, for example) in some portion of the globe at the present day, and not exclusively in Britain.

Errata.

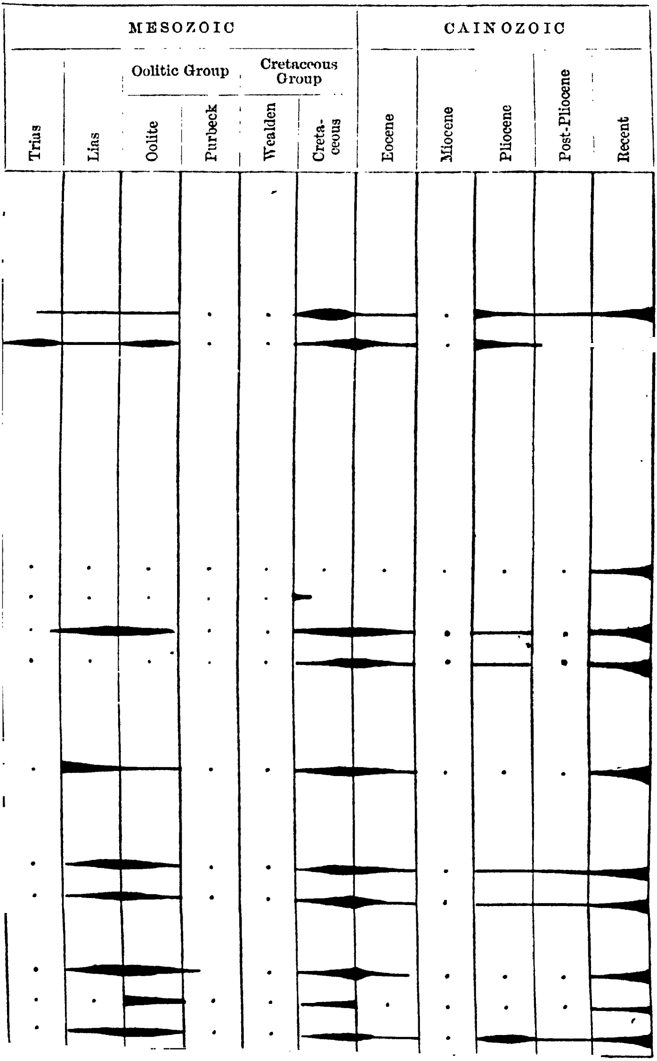
The reader is requested to insert ink-lines in the following places in the table where the presence of fossil forms has been inadvertently omitted:—

ge 630, line 13, erase Copepoda
, ,, line 14, Phyllopoda occur in Trias, Oolite, and Wealden
, ,, lines 19, 20, 24, Phacopidæ, Cheiruridæ, and Calymenidæ occur in Devonian (see text, p. 446)
, 632, ,, 13, 14, Myriapoda and Insecta should stand under Arachnida as classes of equal value. Insecta occur in Lias, Oolite, and Purbeck, and a fragment of a beetle occurs in the Miocene (see text, pp. 230, 321, 350)
, ,, line 23, Rhynchonellidæ occur in Pliocene (see text, p. 175)
, 634, ,, 1, Lingulidæ occur in Cretaceous and Pliocene (see text, p. 181)
, 638, ,, 16, Edaphodontidæ occur in Oolite
, ,, bottom, erase line against Salmonidæ in the Trias
, 640, line 22, Crossopterygidæ are Recent (see text, p. 439)
, ,, lines 5, 23, 24, for *Acanthini*, *Saurodiptermi*, and *Glyptodiptermi*, read *Anacanthini*, *Saurodipterini*, and *Glyptodipterini*
, 642, line 11, Dinosauria occur in Cretaceous
,, ,, 13, Pterosauria occur in Wealden
,, ,, 18, insert Order Sirenia (Halitherium) between Marsupialia and Cetacea. It occurs in Pliocene and Recent (see text, p. 178)
,, ,, 20, insert Delphinidæ under Order Cetacea. They occur in Pliocene and Recent
,, ,, 24, Tapiridæ occur in the Eocene (see text, p. 248)
644, ,, 3, Suidæ occur in Eocene
,, ,, 12, Trichicidæ are Recent

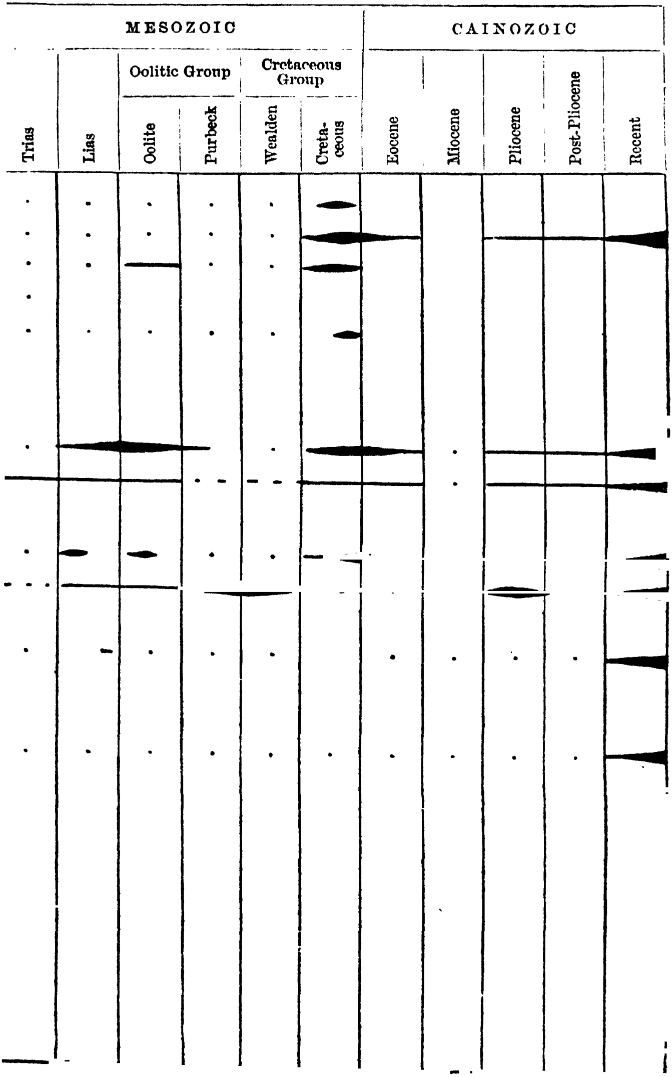
Classes, Orders, and Families	PALÆOZOIC					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Kingdom **PLANTÆ.**						
Class Cryptogamia.						
Cellulares.						
Fam. Algæ	.	▬	▬	.	▬	▬
— Characeæ	.	.	.	.	.	.
Vasculares						
Fam. Equisetaceæ	.	.	.	.	▬	.
— Calamiteæ	.	.	.	▬		.
— Filices	.	.	.	▬	▬	▬
— Osmundeæ	.	.	.	.	.	.
— Lycopodiaceæ	.	.	▬	▬	▬	▬
— Sigillariæ	.	.	.	▬	▬	
Class Phanerogamia.						
Sub-class *Gymnospermia.*						
Fam. Cycadaceæ	.	.	.	.	.	.
— Coniferæ	.	.	.	▬	▬	▬
Sub-class *Monocotyledones.*						
Fam. Cyperaceæ	.	.	.	.	.	.
— Gramineæ	.	.	.	.	.	.
— Naiadaceæ	.	.	.	.	.	.
— Pandanaceæ	.	.	.	.	.	.
— Nipaceæ	.	.	.	.	.	.
— Aroideæ	.	.	.	.	▬	.
— Palmæ	.	.	.	.	.	.
— Typhaceæ	.	.	.	.	.	.
Sub-class *Dicotyledones.*						
Apetalæ.						
Fam. Ceratophylleæ	.	.	.	.	.	.
— Cupuliferæ	.	.	.	.	.	.


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Gr.
Lias
Oolite
Pur-beck
Weal-den
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

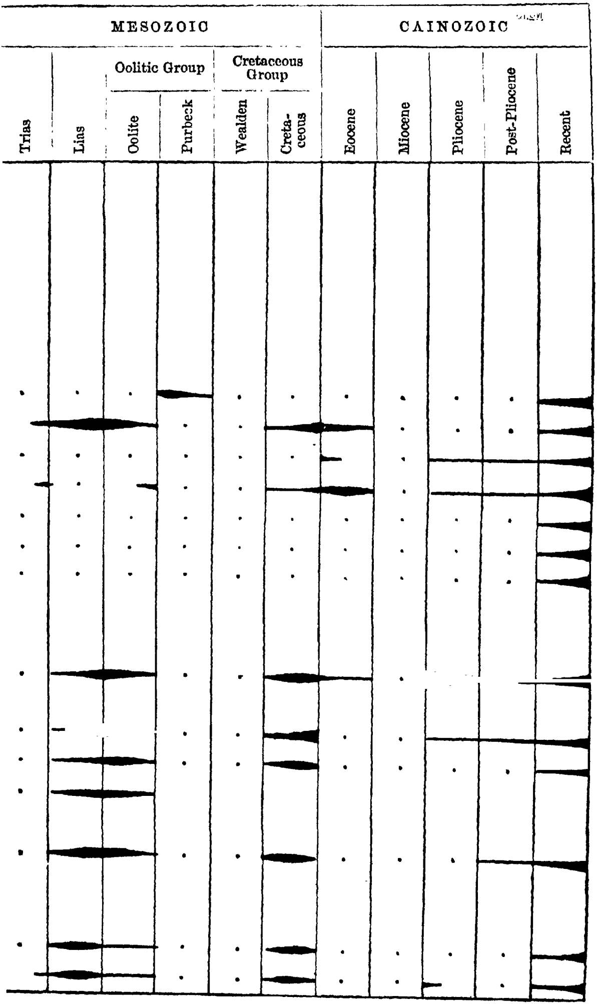
CLASSES, ORDERS, AND FAMILIES	PALÆOZOIC					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
INVERTEBRATA.						
SUB-KINGDOM **Protozoa.**						
Class RHIZOPODA.						
Order Spongida, &c.	━	━	━	━	━	•
— Foraminifera	•	━	━	━	━	━
SUB-KINGDOM **Cœlenterata.**						
Class HYDROZOA.						
Fam. Graptolitidæ	•	━	━			
Class ACTINOZOA.						
Corallaria.						
— Tabulata	•	━	━	━	━	•
— Rugosa	•	━	━	━	━	━
— Aporosa	•	•	•	•	•	•
— Perforata	•	•	•	•	•	•
SUB-KINGDOM **Annuloida.**						
Class ECHINODERMATA.						
Order Crinoidea	━		━	━	━	•
— Cystoidea	•					
— Blastoidea	•	•	•	•	━	
— Ophiuroidea	•	•	━	━	━	•
— Asteroidea	•	━	━	━	•	•
Fam. Palæchinidæ	•	•	•	•	━	
— Cidaridæ	•	•	•	•	•	•
— Cassidulidæ	•	•	•	•	•	•
— Echinidæ	•	•	•	•	•	•


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

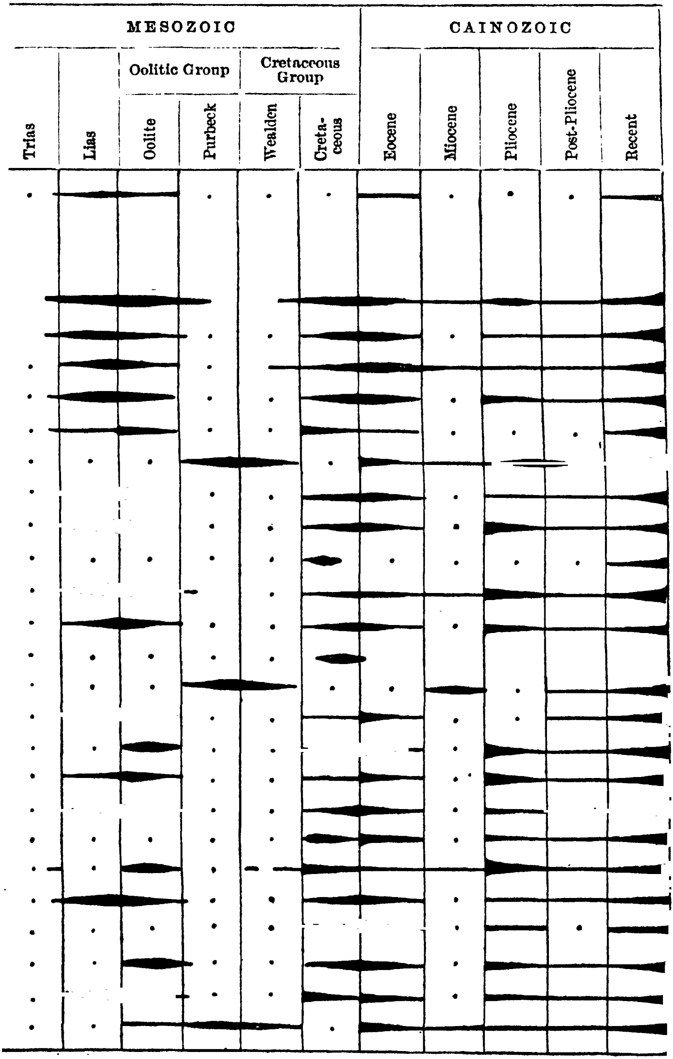
	Classes, Orders, and Families	PALÆOZOIC					
		Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
	Fam. Ananchytidæ . .	·	·	·	·	·	·
	— Spatangidæ . .	·	·	·	·	·	·
	— Galeritidæ . . .	·	·	·	·	·	·
	— Archæocidaridæ .	·	·	·	·	▬	
	— Marsupitidæ . .	·	·	·	·	·	·
	Sub-Kingdom **Annulosa.**						
	Class Annelida.						
	Order Tubicola (*Serpulæ*) .	▬	▬	▬	▬	▬	▬
	— Errantia (*Arenicolæ*) .	▬	▬	▬	▬	▬	▬
	Class Crustacea.						
	Order Cirripedia, &c. . .	·	·	▬	·	·	·
Entomostraca	— Ostracoda . . .		▬	▬	▬	▬	▬
	— Copepoda . .						
	— Phyllopoda . . .	▬	▬	▬	▬	▬	▬ ·
	Merostomata.						
	— Eurypterida . .	·	·	▬	▬	▬	
	— Xiphosura . . .	·	·	▬	·	▬	·
	Group **Trilobita.**						
	Fam. Phacopidæ . .	·	▬	▬			
	— Cheiruridæ . . .	·	▬	▬			
	— Acidaspidæ . .	·	▬	▬			
	— Cyphaspidæ . . .	·	▬				
	— Harpedidæ . .	·	▬	▬	▬		
	— Calymenidæ . . .	·	▬	▬			
	— Conocephalidæ . .	▬	▬				
	— Paradoxidæ . .	▬					


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	PALÆOZOIC Cambrian	 Lower Silurian	 Upper Silurian	 Devonian	 Carboniferous	 Permian
Entomostraca—*continued.* Fam. Olenidæ	━	━				
— Asaphidæ	•	━	━			
— Bronteidæ	•	━	━	━		
— Proteideæ	•	•	━	━	━	
— Trinucleidæ	•	━	━			
— Agnostidæ	━	━				
Sub-Class MALACOSTRACA.						
Order Isopoda	•	•	•	•	•	•
— Macrura	•	•	•	•	━	━
— Anomura	•	•	•	•	•	•
— Brachyura	•	•	•	•	•	•
Class ARACHNIDA.	•	•	•	•	━	•
— Myriapoda	•	•	•	•	━	•
— Insecta	•	•	•	•	━	•
SUB-KINGDOM **Mollusca.**						
DIVISION **Molluscoida.**						
Class POLYZOA	•	━	━	━	━	━
Class Brachiopoda						
Fam. Terebratulidæ	•	•	•	━	━	━
— Thecididæ	•	•	•	•	•	•
— Spiriferidæ	•	•				
— Orthidæ						
— Rhynchonellidæ	•	•	━	━	━	━
— Strophomenidæ	•	━	━	━	━	
— Productidæ	•	•	•	━	━	━
— Craniadæ	•	━	━	━	━	━
— Discinidæ	•	━	━	━	━	━


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Cretaceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

	Classes, Orders, and Families	PALÆOZOIC					
		Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Brachiopoda	Fam. Lingulidæ	▬	▬	▬	▬	▬	▬
	— Calceolidæ	•	•	•	▬		
	Class Lamellibranchiata.						
Asiphonida	Fam. Ostreidæ	•	•	•	•	•	•
	— Aviculidæ	•	▬	▬	▬	▬	▬
	— Mytillidæ	•	▬	▬	▬	▬	▬
	— Arcadæ	▬	▬	▬	▬	▬	▬
	— Trigoniadæ	•	▬	▬	▬	▬	▬
	— Unionidæ	•	•	•	▬	•	•
	— Limidæ	•	•	•	•	•	•
	— Pectinidæ	•	•	•	•	•	▬
Siphonida	Fam. Chamidæ	•	•	•	•	•	•
	— Cardiidæ	•	•	▬	▬	▬	•
	— Lucinidæ	•	•	•	•	•	•
	— Hippuritidæ	•	•	•	•	•	•
	— Cycladidæ	•	•	•	•	•	•
	— Cyprinidæ	•	•	•	▬	▬	▬
	— Veneridæ	•	•	•	▬	•	•
	— Mactridæ	•	•	•	•	•	•
	— Tellinidæ	•	•	▬	▬	▬	▬
	— Solenidæ	•	•	▬	•	▬	▬
	— Myadæ	•	•	▬	▬	▬	•
	— Anatinidæ	•	•	▬	•	▬	▬
	— Gastrochænidæ	•	•	•	•	•	•
	— Pholadidæ	•	•	•	•	▬	•
	— Nuculidæ	▬	▬	▬	▬	▬	▬
	— Cyrenidæ	•	•	•	•	•	•


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

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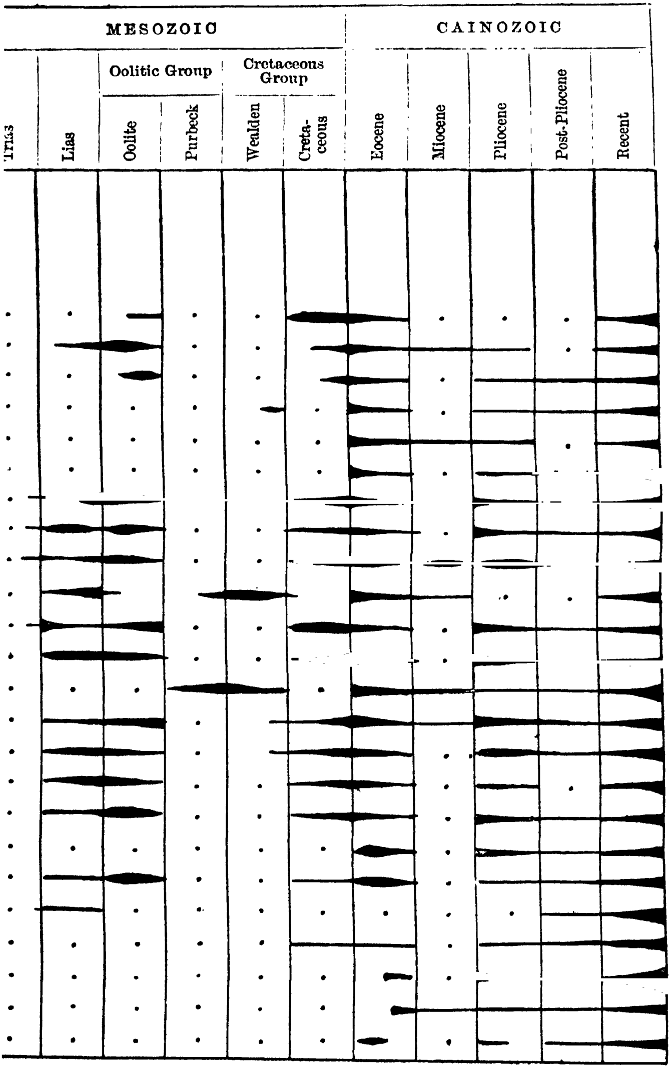
		Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Nucleobranchiata	Fam. Bellerophontidæ		▬	▬	▬	▬	
	— Atlantidæ	▬	▬	▬	▬	▬	
	Class Gasteropoda.						
Siphonostomata	Fam. Strombidæ	.	.	.	.	.	.
	— Muricidæ	.	.	.	.	.	.
	— Buccinidæ	.	.	.	– –	– –	.
	— Conidæ	.	.	.	.	.	.
	— Volutidæ	.	.	.	.	.	.
	— Cypræidæ	.	.	.	.	.	.
Holostomata	— Naticidæ	.	.	▬	▬	▬	.
	— Pyramidellidæ	.	.	▬	▬	▬	.
	— Cerithiadæ	.	.	.	.	.	.
	— Melaniadæ	.	.	.	.	.	.
	— Turritelidæ	.	.		▬	▬	.
	— Littorinidæ	.	.	.	.	▬	.
	— Paludinidæ	.	.	.	.	.	.
	— Neritidæ	.	.	▬	▬	▬	.
	— Turbinidæ	.	▬				▬
	— Haliotidæ	.	▬	▬	▬	▬	.
	— Fissurellidæ	.	.	.	.	.	.
	— Calyptreidæ	.	.	▬	▬	▬	.
	— Patellidæ	.	.	▬	.	▬	.
	— Chitonidæ	.	.	▬		▬	.
	— Dentaliadæ	.	.	.	.	▬	▬
Inoperculata	— Helicidæ	.	.	.	.	.	.
	— Limnæidæ	.	.	.	.	.	.
	— Auriculidæ	.	.	.	.	.	.


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Trias
Lias
Oolite
Purbeck
Wealden
Cretaceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

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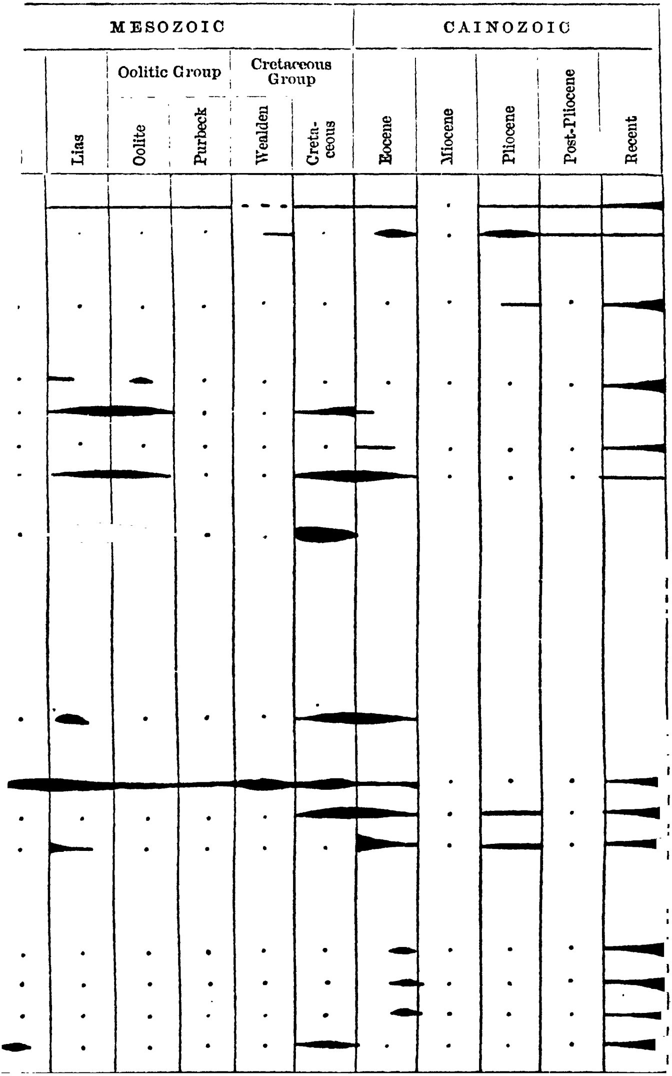
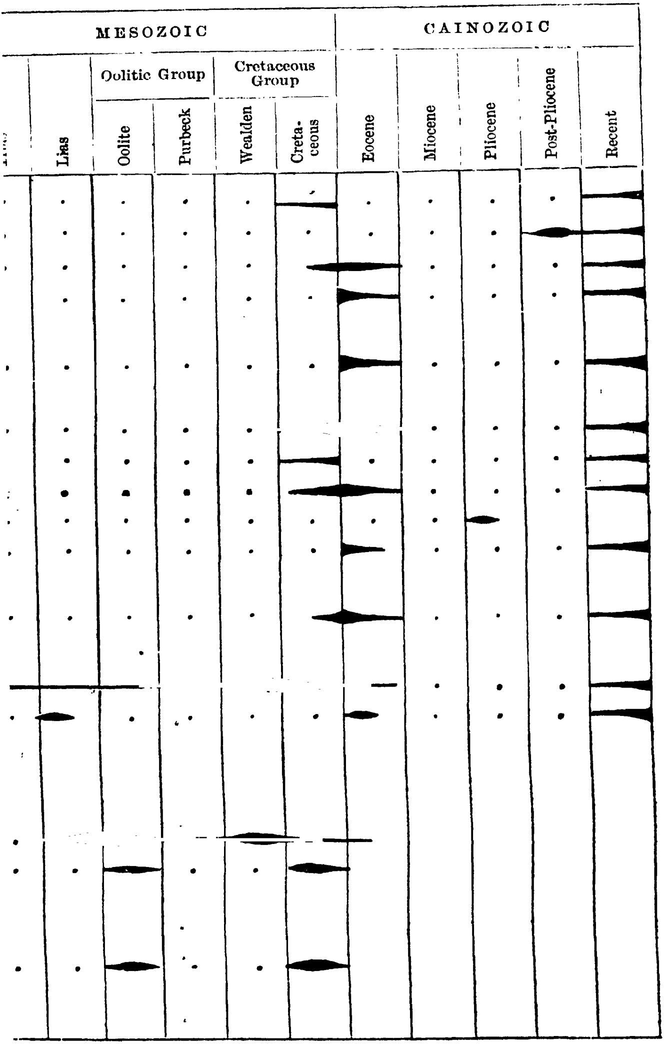
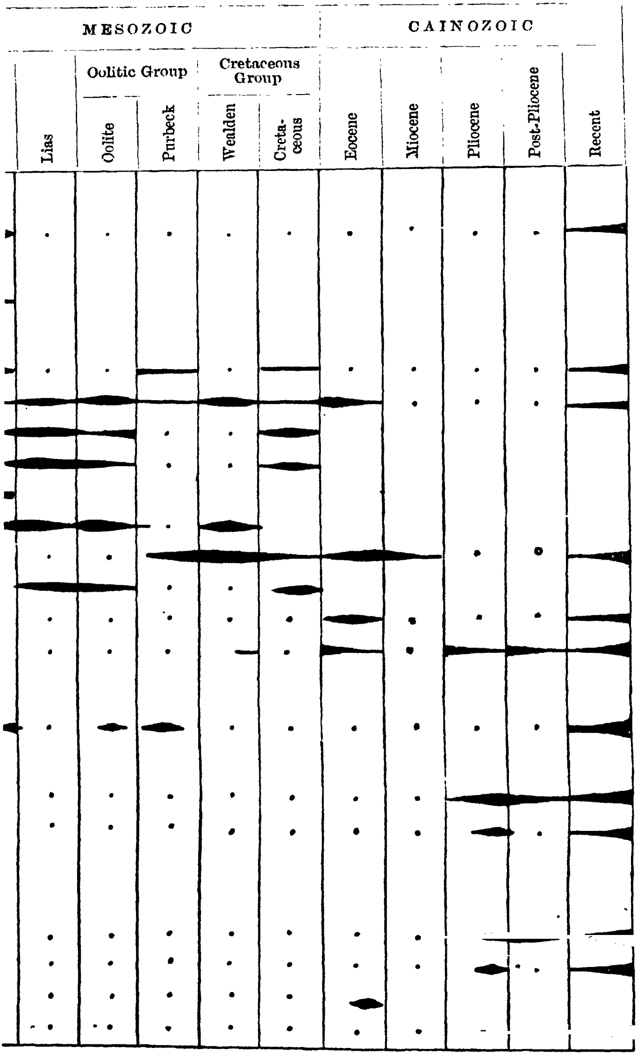
Tectibranchiata	Fam. Tornatellidæ	•	•	•	•	•	•
	— Bullidæ	•	•	•	•	•	•
Class Pteropoda.							
	Fam. Hylcidæ	•			━	━	━
Class Cephalopoda.							
Dibranchiata	Fam. Teuthidæ	•	•	•	•	•	•
	— Belemnitidæ	•	•	•	•	•	•
	— Sepiadæ	•	•	•	•	•	•
Tetrabranchiata	— Nautilidæ	•	━	━	━	━	━
	— Orthoceratidæ	━	━	━	━	━	
	— Ammonitidæ	•	•	•	•	━	•
VERTEBRATA.							
Class **Pisces.**							
Order Elasmobranchii.							
Sub-Order *Holocephali.*							
	Fam. Edaphodontidæ	•	•	•	•	•	•
Sub-Order *Plagiostomi.*							
	Fam. Cestraphori	•	•	• ━	━	━	━
	— Squalidæ (Selachii)	•	•	•	•	•	•
	— Raidæ	•	•	•	•	━	•
Order Teleostei.							
Sub-Order A. *Malacopteri.*							
	Fam. Siluridæ	•	• ━	•	•	•	•
	— Cyprinidæ	•	•	•	•	•	•
	— Characini	•	•	•	•	•	•
	— Salmonidæ	•	•	•	•	•	•


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Lias
Oolite
Purbeck
Wealden
Cretaceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

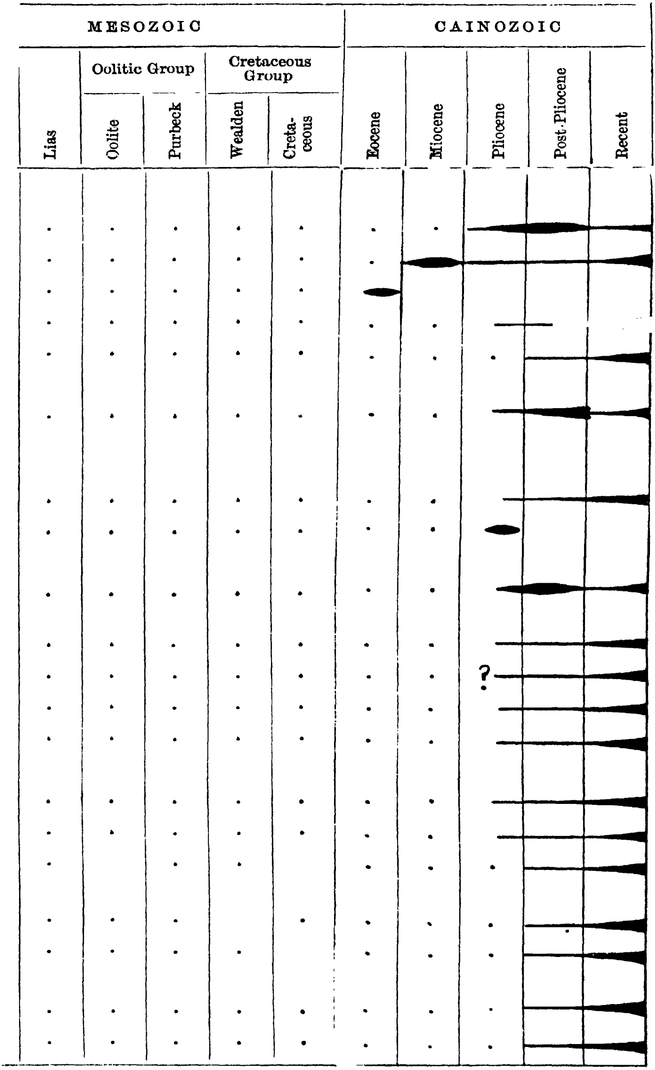
Classes, Orders, and Families	PALÆOZOIC					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Fam. Scopellidæ	.	.	.	.	.	.
— Esocidæ	.	.	.	.	.	.
— Clupeidæ	.	.	.	.	.	.
— Murænidæ	.	.	.	.	.	.
Sub-Order B. *Acanthini.*						
Fam. Gadidæ	.	.	.	.	.	.
Sub-Order C. *Acanthopteri.*						
Fam. Percidæ	.	.	.	.	.	.
— Mugilidæ	.	.	.	.	.	.
— Scomberidæ	.	.	.	.	.	.
— Squammipennes	.	.	.	.	.	.
— Lophiidæ	.	.	.	.	.	.
Sub-Order D. *Pharyngognathi.*						
Fam. Scomberesocidæ	.	.	.	.	.	.
Order Ganoidei.						
Sub-Order *Lepidosteidæ* (*Sauroidei*)	.	.	.	▬	▬	▬
Fam. Chondrosteidæ	.	.	.	.	.	.
— Cephalaspidæ	.	.	▬	▬		
— Placodermi	.	.	.	▬		
— Acanthodidæ	.	.	.	▬	▬	
— Pycnodontidæ	.	.	.	.	▬	▬
— Crossopterigidæ	.	.	.	▬	▬	▬
— Saurodiptermi	.	.	.	▬	▬	
— Glyptodiptermi	.	.	.	▬	▬	
— Cœlacanthini	.	.	.	.	▬	▬
— Phaneropleurini	.	.	.	▬		
— Ctenodipterini	.	.	.	▬		


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	PALÆOZOIC					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Order Dipnoi.						
Fam. Sirenidæ (*Ceratodus*)	.	.	.	.	.	.
Class **Amphibia.**						
Order Labyrinthodontia	.	.	.	.		
Class **Reptilia.**						
Order Lacertilia	.	.	.	.	.	
— Crocodilia	.	.	.	.	.	.
— Ichythopterygia	.	.	.	.	.	.
— Sauropterygia	.	.	.	.	.	.
— Anomodontia	.	.	.	.	.	.
— Deinosauria	.	.	.	.	.	.
— Chelonia	.	.	.	.	.	.
— Pterosauria	.	.	.	.	.	.
— Ophidia	.	.	.	.	.	.
Class **Aves**	.	.	.	.	.	.
Class **Mammalia.**						
Order Marsupialia	.	.	.	.	.	.
Order Cetacea.						
Fam. Balænidæ		.	.	.	.	.
— Rhynchocœti	.	.	.	.	.	.
Order Ungulata.						
Sec. A. *Perissodactyla.*						
Fam. Rhinoceridæ	.	.	.	.	.	.
— Tapiridæ	.	.	.	.	.	.
— Palæotheridæ	.	.	.	.	.	.
— Equidæ	.	.	.	.	.	.


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Lias
Oolite
Purbeck
Wealden
Cretaceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent

Classes, Orders, and Families	PALÆOZOIC					
	Cambrian	Lower Silurian	Upper Silurian	Devonian	Carboniferous	Permian
Sec. B. *Artiodactyla.*						
Fam. Hippopotamidæ	.	.	.	.	.	.
— Suidæ	.	.	.	.	.	.
— Anoplotheridæ	.	.	.	.	.	.
— Cervidæ	.	.	.	.	.	.
— Bovidæ	.	.	.	.	.	.
Order PROBOSCIDEA.						
Fam. Elephantidæ	.	.	.	.	.	.
Order CARNIVORA.						
Sec. 1. *Pinnigrada.*						
Fam. Phocidæ	.	.	.	.	.	.
— Trichicidæ	.	.	.	.	.	.
Sec. 2. *Plantigrada.*						
Fam. Ursidæ	.	.	.	.	.	.
Sec. 3. *Digitigrada.*						
Fam. Mustellidæ	.	.	.	.	.	.
— Hyænidæ	.	.	.	.	.	.
— Canidæ	.	.	.	.	.	.
— Felidæ	.	.	.	.	.	.
Order RODENTIA.						
Fam. Leporidæ	.	.	.	.	.	.
— Castoridæ	.	.	.	.	.	.
— Muridæ	.	.	.	.	.	.
Order CHEIROPTERA.						
Fam. Vespertilionidæ	.	.	.	.	.	.
— Rhinolophidæ	.	.	.	.	.	.
Order INSECTIVORA.						
Fam. Talpidæ	.	.	.	.	.	.
— Soricidæ	.	.	.	.	.	.


MESOZOIC
CAINOZOIC
Oolitic Group
Cretaceous Group
Lias
Oolite
Purbeck
Wealden
Creta-ceous
Eocene
Miocene
Pliocene
Post-Pliocene
Recent
?

INDEX.

The Fossils, the names of which are printed in Italics, are figured in the Text.

ABBEVILLE, flint tool, figure of, 130
Abich, M., on trachytic rocks, 503
Acer trilobatum, Miocene, 202, 203
Acid rocks, term explained, 497
Acrodus nobilis, Lias, 346
Acrogens, term explained, 287
—— coal period an age of, 413
Acrolepis Sedgwickii, Permian, 380
Actæon acutus, Great Oolite, 332
Actinocyclus in Atlantic mud, 271
Actinolite, 498, 501
—— schist, 578
Æchmodus *Leachii*, Lias, 345
Adiantites Hibernica, Old Red, 437
Agassiz on fish of Sheppey, 250
—— on fish of the Brown-Coal, 541
—— on fish of Monte Bolca, 543
—— on living Voluta, 177
—— on fish of the Lias, 345
—— on heterocercal fish-tails, 379
—— on Old Red fossil fish, 438, 443
—— on Silurian fish, 544
Age of metamorphic rocks, 599
—— of Plutonic rocks, 565
—— of strata, tests of, 100
—— of volcanic rocks, 520
Agglomerate described, 508
Agnostus integer. A. Rex, 487
Air-breathers of the coal, 406
Airdrie, glacial shells of, 156
Aix-la-Chapelle, Cretaceous flora of, 205, 285
Alabaster defined, 14
Alberti on Keuper, 365
Albien of French, Cretaceous series, 266
Albite, 498, 500
Aldeby and Chillesford beds, 172
Alkali, present in the Palæozoic strata, 587
Alleghany Mts., thickness of Palæozoic rocks in, 87
—— bituminous coal of, 395
Alpine blocks on the Jura, 147
Alps, age of metamorphic rocks in, 601
—— nummulitic limestone and flysch of, 260
Alum schists of Norway and Sweden, 488
Alluvial deposits, Recent and Pleistocene, 128
Alluvium, term explained, 76
—— in Auvergne, 77
Alternations of marine and freshwater strata, 49
Alum Bay beds, plants of the, 245
Amblyrhynchus cristatus, a living marine saurian, 349
America, North, Glacial formations of, 162
—— S., gradual rise of land in, 49
—— Silurian strata of, 477
—— *See* United States, Canada, Nova Scotia
American character of Swiss Lower Miocene flora, 222
American coal-measures, footprints in, 400
Amici, Prof., on Chara, 34
Amiens, flint tools of, 129
Ammonites of the Gault, 285
Ammonites bifrons, Lias, 343
—— *Braikenridgii, Oolite*, 338
—— *Bucklandi, Lias*, 343
—— *Deshayesii, Neocomian*, 296
—— *Humphresianus, Inf. Oolite*, 338
—— *Jason, Oxford Clay*, 327
—— *Noricus, Specton*, 297
—— *macrocephalus, Oolite*, 338
—— *margaritatus, Lias*, 344
—— *planorbis, Lias*, 343
—— *Rhotomagensis, Chalk marl*, 282
Amphibia, Carboniferous, 397
Amphibole group of minerals, 498, 501
Amphistegina Hauerina, Vienna basin, 208
Amphitherium Broderipii, in Stonesfield, 335
—— *Prevostii, Stonesfield slate*, 334
Ampullaria glauca, 32
Amygdaloid, 506
Analcime, 499
Anamesite, a variety of basalt, 504
Ananchytes ovatus. White chalk, 276
—— *with crania attached*, 25
Ancillaria subulata, Eocene, 33
Ancyloceras gigas, 293
—— *spinigerum, Gault*, 284
—— *Duvallei, Neocomian*, 296
Ancylus velletia (*A. elegans*), 31
Andalusite, 499
Andes, Plutonic rocks of the, 570
Andreasburg, metalliferous vein of, 613

Angelin, on Cambrian of Sweden, 488
Angiosperms, 287
Anglesea, dike cutting through shale in, 514
Annularia sphenophylloides, coal, 419
Anodonta Cordierii, 30
—— *Jukesii*, Upper Old Red, 436
—— *latimarginata*, 30
Anoplotherium commune, *Binstead*, 237
—— *gracile*, *Paris basin*, 255
Anorthite, 498, 500
Antholithes, coal-measures, 423
Anthophyllum lineatum, 211
Anthracite, conversion of coal into, 394
Anticlinal and synclinal curves, 51, 62
Antrim, Chalk altered by a dike in, 515
—— Lower Miocene, volcanic rocks of, 539
—— Potstones in chalk of, 275
Antwerp Crag, 185
Apateon pedestris, a carboniferous reptile, 397
Apatite, 499
Apennines, Northern, metamorphic rocks of, 601
Apes, fossil of the Upper Miocene, 196
Apiocrinites rotundus, *Bradford*, 329
Apiocrinus with serpulæ attached, 330
Aporrhais Sowerbyi, *Thanet Sands*, 253
Appalachians, long lines of flexures in, 69, 70
—— vast thickness of successive strata in, 87
Aptychus, part of ammonite, 323
Aqueous rocks defined, 3–11
—— tests of different ages of, 100–107
Araucaria sphærocarpa, *Inf. Oolite*, 335
Arbroath, section of Old Red at, 51
—— paving-stone, 439, 442
Archæopteryx macrura, *Solenhofen*, 325
Archegosaurus minor and A. medius, coal-measures, 398
Archiac, M. d', on nummulites, 259
—— on chalk of France, 289
Arctic Miocene Flora, 222
—— Cretaceous Flora, 305
Arctocyon primævus in Eocene of France, 260
Area of the Wealden, 304
Areas, permanence of continental, 94
Arenaceous rocks described, 11
Arenicolites in Queenaig Palæozoic strata, 89
Arenicolites linearis, Arenig beds, 474
Arenig or Stiper-Stones group, 474
—— volcanic formations of, 550
Argile plastique, 259
Argillaceous rocks described, 12
Argillite, Argillaceous schist, 579
Argyll, Duke of, on Isle of Mull leaf beds, 230
—— on Miocene lavas, 525
Armagh, bone beds in Mountain Limestone at, 432
Arran, amygdaloid filled with spar near, 518
—— erect trees in volcanic ash of, 547
—— Greenstone dike in, 513
Arthur's Seat, trap rocks of, 546
Arvicola, tooth of, 143
Asaphus caudatus, Silurian, 464
Asaphus tyrannus, *A. Buchii*, 473
Ascension, lamination of volcanic rocks in, 596
Ash, Mr., on fossils of Tremadoc beds, 482
Ashburnham beds, 300
Ashby-de-la-Zouch, fault in coal-field of, 68
Ashdown Sand, 300
Aspidura loricata, *Muschelkalk*, 369
Astarte borealis (=*A. arctica*=*A. compressa*), 156
—— *Omalii*, *Crag*, 180
Asterophyllites foliosus, *Coal*, 418
Astrangia lineata (*Anthophyllum lineatum*), 211
Astræa basaltiforme, Carboniferous, 427
Astropecten crispatus, *London clay*, 250
Atanekerdluk, Miocene Flora of, 223
Atherfield clay, 293
Atlantic mud, composition of, 271
Aturia ziczac (*Nautilus ziczac*), 249
Atrypa reticularis, Aymestry, 459
Augite, 498, 501
Auricula, recent, 31
Aust, Rhætic beds of, 355
Austen, Mr. Godwin, on marine deposit of Selsea Bill, 161
—— on Neocomian, 294
—— on boulders in chalk, 276
Australian cave breccias, 136
Australia, auriferous gravel of, 617
—— extinct marsupials of, 136
Auvergne, alluvium in, 77
—— chain of extinct volcanos in, 495
—— freshwater strata of, 29
—— granite veins in, 613
—— Lower Miocene of, 215
—— Miocene volcanic rocks of, 541
—— Pleistocene volcanic eruptions in, 527
—— springs from spent volcanos, 586, 606
Aveline, Mr., on Tarannon shales, 466
Avicula contorta, *Rhætic beds*, 354
—— *cygnipes*, *Lias*, 342
—— *inæquivalvis*, *Lias*, 342
—— *socialis*, *Muschelkalk*, 369
Aviculopecten papyraceus, coal-measures, 396
—— *sublobatus*, mountain limestone, 429
Axinus angulatum, 250
Aymard, M., on mammalia of the Limagne, 217
Aymestry Limestone, 459
Azoic period, supposed, 605
Azores, Miocene lavas with shells, 539

BACILLARIA paradoxa, 27
Baculites anceps, *Lower Chalk*, 281
—— *Faujasii*, chalk, 269
Baffin's Bay, Icebergs carrying blocks in, 150
Bagshot Sands, 235, 243, 245
Bahr Assal, salt lake, 364
Baiæ, Bay of, subterranean igneous action in, 526, 570
Bakewell, Mr., on cleavage in Swiss Alps, 591
Bala and Caradoc beds, 468
Balistidæ, defensive spine of, 244

Bangor, or Longmynd group, 485
Banksia, fruit and leaf of, Miocene, 221
Barmouth sandstones, 487
Barnes, Mr. J., on insects in American coal, 408
Barnstaple, Upper Devonian of, 446
Barrande, M. Joachim, his 'Primordial Zone,' 481, 484
—— on metamorphosis of trilobites, 469
—— on Silurian fossils of Bohemia, 469
Barrett, Mr., on bird in Coprolite bed, 283
Barton series, percentage of shells common to London clay, 241
Basalt, columnar, 511
—— composition of, 503
Basaltic rocks, poor in silica, 497, 503
—— specific gravity of minerals in, 503
Basic rocks, term explained, 497
Basilosaurus, Eocene, United States, 263
Basle, Loess of, 133
Basset, term explained, 60
Basterot, M. de, on Bordeaux tertiary strata, 118
Bateman, Mr., on drift shells near Manchester, 161
Bates, Mr., on banks of dead insects, 200
Bath Oolite, 328
Bathybius, fossils of the chalk, 271
Bay of Fundy, denudation in coal-field in, 411
Bean, Mr., on Yorkshire Oolite, 337
Bear Island, carboniferous flora, 437
Beaumont, M. E. de, on island in Cretaceous sea, 289
—— on mineral veins, 616
—— on Jurassic plutonic rocks, 572
—— on formation of granite, 554
Beckles, Mr. S. H., on footprints in Weald Clay, 300, 316
—— on Mammalia of Purbeck, 312, 314
Belemnitella mucronata, chalk, 266
Belemnites hastatus, Oxford clay, 327
—— *Puzosianus, Oxford clay*, 327
Belgium, Miocene of, 206, 224
Bellerophon costatus, Mountain Limestone, 430
Belosepia sepioidea, Sheppey, 249
Belt, Mr., on subdivision of Lingula Flags, 483
—— on cause of rich cappings in gold veins, 620
—— on origin of gold veins, 620
—— on classification of Menevian, 484
Bembridge beds, Yarmouth, 235
Berger, Dr., on rocks altered by dikes, 515
Berlin, Miocene strata near, 225
Bernese Alps, gneiss in the, 601
Berthier on isomorphism, 502
Bertrich-Baden, columnar basalt of, 511
Better-bed coal, section of, 404
Beyrich on term Oligocene for Lower Miocene, 227
—— on transition Miocene beds, 227
Bilin, tripoli of, 27
Billings, Mr., on trilobites, 470
Bingen, Loess of, 133
Binney, Mr., on Sigillariæ in volcanic ash, 547
—— on Permian footprints, 381

Binney, Mr., on Stigmaria, the root of gillaria, 420
Biotite, 498, 501
Bird in argile plastique, 260
—— footprints in Trias of Connecticut, 371
—— in Coprolite bed of Chloritic series, 283
Birds of Paris basin, 254
Bischoff, Professor, on Nile and Rhine mud, 131
—— on conversion of coal into anthracite, 394
—— on hydrothermal action, 587
Blackdown beds, 285
Blackheath, London clay under marine beds at, 252
Blacklead of Borrowdale, 42
Blocks, Alpine, on the Jura, 147
Boase, on composition of clay, 12
Bog-iron-ore, 28
Bohemia, Cambrian rocks of, 487
—— Silurian rocks of, 469, 477
—— silver veins in, 618
Bolderberg, in Belgium, Miocene of, 206
Bone-bed of fish remains, Armagh and Bristol, 431, 432
—— of Upper Ludlow, 456
—— of the Trias, 357
Boom, Lower Miocene of, 224
Bordeaux, Upper Miocene of, 195
Borrowdale, blacklead of, 42
Bosquet, M., on Maestricht beds, 267
Botanical nomenclature, 287
Boucher de Perthes on Abbeville alluvium, 129
Boulder-clay, 144
Boulder-clay of Canada, 162
——fauna of, 156
Boulders and pebbles in chalk, 275
Bournemouth beds (Lower Bagshot), 245
Bovey Tracey, lignites and clays of, 229
Bowerbank, Mr., on fossil fruits of Sheppey, 248
Bowman, Mr., on uniting of distinct coal-seams, 392
Brachiopoda, preponderance of, in older rocks, 468
—— mode of recognising shells of, 469
—— of the White Chalk, 278
Brachiopods, Silurian period, the age of, 479
Bracklesham beds and Bagshot Sands, 243
Bradford Encrinites, 330
Breccia described, 12
Breccias of Lower Permian, 381
Brick-earth or fluviatile loam, 130
Bridlington drift, 169
Bristol, dolomitic conglomerate of, 361
—— carboniferous bone-bed near, 432
Bristow, Mr., on volcanic minerals, 499
Brixham cave near Torquay, 135
Brocchi on Italian tertiary strata, 118
—— on subapennine strata, 190
Brockenhurst, corals and shells of, 240
Broderip, Mr., on Stonesfield Mammalia, 335
Brodie, Rev. P. B., on Lias insects, 350
Brodie, Mr. W. R., on Purbeck mammalia, 312
Brongniart, M. Adolphe, on botanical nomenclature, 287

Brongniart, M. Adolphe, on Lias plants, 351
—— on flora of the Bunter, 370
—— on flora of the coal, 413, 419
—— on fruit of Lepidodendron, 417
—— M. Alex., on Tertiary series, 118
Bronteus flabellifer, Devonian, 449
Bronze weapons of lake-dwellings, 125
Bronzite, 498, 501
Brora, oolitic coal formation of, 337
Brown, Mr. Richard, on Stigmaria, 420
—— on carboniferous rainprints, 410
—— Robert, on Eocene proteaceous fruit, 248
—— Rev. T., on marine shells in Scotch drift, 157
Brown-coal of Germany, 540
Bryce, Mr., on Scotch till, 156
Bryozoa of Mountain Limestone, 427
—— and polyzoa, terms explained, 178
—— of the white chalk, 279
Buch, Von. *See* Von Buch.
Buckland, Dr., on Kirkdale cave, 135
—— on violent death of saurians, 349
—— on spines of fish, 317
—— on Eocene oysters, 251
—— on potstones in chalk, 275
—— on chalk coprolites, 281
—— on preservation of lower jaws, 314
Buckley, Dr., on Alabama Zeuglodon, 263
Buddle, Mr., on creeps in coal-mines, 55
Bulimus ellipticus, *Bembridge*, 236
—— *lubricus*, Loess, 32
Bullock, Capt., R.N., on Atlantic mud, 271
Bunbury, Sir C., on leaf-bed of Madeira, 533
—— on ferns of the Maryland coal, 414
Bunter of Germany, 370
—— or Lower Trias of England, 360
Buprestis? Elytron of, *Stonesfield*, 333
Burmeister on trilobites, 469

CAINOZOIC, term defined, 100
Caithness, fish-beds of, 438
Calamite, root of, 418
Calamites Sucowii, coal, and restored stem, 417
Calamophyllia radiata, *Bath Oolite*, 329
Calcaire de la Beauce, age of the, 213
—— grossier, fossils of the, 257
—— siliceux of France, 257
Calcareous matter poured out by springs, 606
—— rocks described, 12
—— nodules in Lias, 40
Calcarina rarispina, *Eocene*, 258
Calceola sandalina, Devonian, 449
Calceola schiefer of Germany, 450
California, auriferous gravel of, 618
Calymene Blumenbachii, Silurian, 464
Cambrian Group, classification of the, 480
Cambrian, Upper, 481
—— Lower, 484
—— of Sweden and Norway, 488
—— strata of Bohemia, 487
—— metamorphic rocks, 602
—— of North America, 489
—— volcanic rocks, 550
Campophyllum flexuosum, 426

Canada, Cambrian of, 489
—— Devonian of, 457
—— Devonian, insects of, 453
—— Trap rocks of, 550
—— metamorphic rocks of, 602
Canadian drift, 162
Canary, Grand, shelly tuffs of, 538
—— Islands, laterite of, 509
Cantal, Lower Miocene of the, 214
Canham, Rev. H., cited, 178
Cape Breton, rainprints in coal-measures of, 409
—— of Good Hope, granite veins at, 560
—— Wrath, granite veins in gneiss at, 560
Caradoc and Bala beds, 468
Carbonate of lime in rocks, how tested, 13
Carboniferous Group, subdivisions of, 385
—— flora, 413–425
—— limestone, thickness of, 386
—— marine fauna of the, 425
—— Period, trap rocks of, 546
—— plutonic rocks, 573
—— amphibia, 397
—— insects, 396
—— strata, folding and denudation of, 410
—— corals, 425
Carcharodon angustidens, *Bracklesham*, 245
Cardiganshire, section of slaty cleavage in, 590
Cardiocarpon Ottonis, *Permian*, 383
—— *Lindleyi*, 423
Cardita (*Venericardia*) *planicosta*, 243
—— *sulcata*, *Barton*, 242
Cardium dissimile, *Portland Stone*, 322
—— *rhæticum*, *Rhætic Beds*, 354
—— *striatulum*, *Kimmeridge clay*, 322
Carne, Mr. N., on Cornish lodes, 610
Carpathians, nummulitic limestone of, 261
Carpenter, Dr., on Atlantic mud, 271
—— on Eozoon Canadense, 491
—— on Orbitoides, 262
Carrara, marble of, 601
Carruthers, Mr., on Eocene proteaceous fruit, 248
—— on Cardiocarpon, 423
—— on cycads of the Purbeck, 318
—— on leaves of calamite, 419
—— on spores in coal, 405
—— on spores of carboniferous Lycopodiaceæ, 415
—— on structure of sigillaria, 420
—— on trees in volcanic ash, 547
Cashmere, recent formations in, 123
Caspian Sea, stunted fauna of, 435
Cassian, St., Triassic strata of, 366
Castrogiovanni, curved strata near, 63
Catania, laterite formed in, 509
—— Tertiary beds in, 187
Catillus Lamarckii, *White Chalk*, 278
Caucasus, absence of lakes in the, 167
Caulopteris primæva, coal, 414
Cautley, Sir Proby, on fauna of Siwâlik Hills, 209
Cave-breccias of Australia, 136
Cavern deposits, with human and animal remains, 133
Caves of Kirkdale and Brixham, 135
Celt described and figured, 130

Cementing of strata, 38
Cénomanien of French Cretaceous series, 266
Cephalaspis Lyelli, Old Red, 442
Ceratites nodosus, *Muschelkalk*, 369
Cerithium concavum, *Headon*, 239
—— *elegans*, *Hempstead beds*, 228
—— (*Terebra*) *Portlandicum*, 321
—— *plicatum*, *Hempstead beds*, 228
—— *melanoides*, 251
—— *funatum*, 31
Cervus alces, tooth of, 142
Cestracion Phillippi, *Recent*, 280
Cetacean of United States, Eocene, 263
Chabasite, 499
Chalk, composition, extent, and origin of, 269
Chalk of Faxoe, 269
—— flints, origin of, 273
—— fossils of the White, 276–279
—— iceborne boulders in the, 275
—— of North and South of Europe, 288
—— Lower White, without flints, 281
—— marl, fossils of the, 281
—— Period, popular error concerning, 272
—— vitreous sponges of the, 274
Challenger, H.M. ship, dredgings by, 539
Chalkpit with potstones, view of, 274
Chama squamosa, *Barton*, 241
Champoleon, junction of granite with Jurassic strata near, 572
Chara elastica, *C. medicaginula*, 34
—— *tuberculata*, *Bembridge*, 236
Charpentier, M., on Alpine glaciers, 148
—— on depression of Alps in Glacial Period, 165
Chatham coal-field, 373
Cheirotherium, *footprints of*, 360
Cheltenham, Inferior Oolite of, 336
Chemical deposits in veins, 615
—— and mechanical deposits, 37
Cheshire, slab of ripple-marked sandstone from, 21
—— rock-salt of, 362
Chiapa, fall of volcanic dust at, 523
Chili, copper pyrites with gold in, 619
—— walls cracked by earthquake in, 64
Chichester, erratics near, 161
Chillesford and Aldeby beds, 172
Chimæra monstrosa, *Lias*, 346
Chlorite, 498
Chlorite-schist, 579
Chloritic series, or Upper Greensand, 282
Christiania, Euritic porphyry at, 552
—— granite altering strata in, 582
—— granite veins in Silurian strata of, 573
—— quartz vein in gneiss at, 552
Chronological groups of formations, 106
Chronology, test of, in rocks, 98
Cinder-bed of the Purbeck, 311
Cinnamomum polymorphum, Miocene, 201
—— *Rossmässleri*, Miocene, 221
Claiborne beds, Eocene fossils of, 262
Clarke County, United States, Zeuglodon of, 263
Classification of Tertiary formations, 114
—— of rocks, 3
—— value of shells in, 119
Clausilia bidens, Loess, 32
Clay defined, 12
—— iron-stone defined, 395
—— plastic, 250
—— slate, 579
—— slate, lamination of, 597
—— Weald, 298
Cleavage explained, 501
—— crystalline theory of, 592
—— mechanical theory of, 593
—— slaty, 589
—— sections of, 590, 591
Cleidotheca operculata, 482
Clermont, metalliferous gneiss near, 583
Climate of the crags, 181
—— of the coal, 425
—— of the Miocene in Arctic regions, 223
—— of the Pleistocene period, 138
Clinkstone, 505
Clinton group, fossils of the, 478
Cluses, causes of, 60
Clyde, buried canoes in estuary of, 123
—— arctic marine shells in drifts of, 156
Clymenia linearis, Devonian, 447
Clymenien-Kalk of Germany, 417
Coal, conversion into anthracite of, 394
—— a land and swamp formation, 388
—— cause of the purity of, 393
—— ferns of the, 414
—— conversion of lignite into, 394
—— erect trees in, 401
—— period, climate of the, 425
—— period, corals of the, 425
—— structure of the, 405
—— vegetation of the, 413
—— air-breathers in the, 406
—— amphibians of the, 397
—— field of Virginia, 372
—— measures of Nova Scotia, 400
—— measures, thickness of in Wales, 383
—— pipes, danger of, 390
—— rainprints in, 409
—— seams, uniting of, 391
—— spores and sporangia of, 404
—— strata, folding and denudation of, 410
Coalbrook Dale, coal-plants of, 417
—— faults in, 66
Coccoliths, 271
Cochliodus contortus, 432
Cockfield Fell rocks, altered by dikes, 516
Cœlacanthus granulatus, *Permian*, 380
Coleoptera of Œningen beds, 206
Collyrites ringens, *Inf. Oolite*, 337
Columnar structure of volcanic rocks, 509
—— basalt in the Vicentin, 511
Compact felspar, 500
Compsognathus in Stonesfield slate, 324
Concretionary structure, 40
Condamine, M. de la, cited, 251
Cone of Tartaret, 527, 542
—— of Côme, 528
Cones and craters described, 494
Cones, absence of, in England, 6
Conformable stratification, 15
Conglomerate or pudding-stone, 12, 508
—— Dolomitic of Bristol, 361
Coniferæ of the coal-measures, 421
Connecticut Valley, New Red Sandstone of, 371
Conocoryphe striata, 487

Conrad, Mr., on age of American cretaceous rocks, 291
Consolidation of strata, 38
Continental ice of Greenland, 150
Continents and oceans, permanence of, 91
Continent, Permian rocks of the, 382
Contorted strata, in drift, 158
Conulus priscus, coal, 408
Conus deperditus, Brackleshan, 215
Conularia ornata, Devonian, 449
Conybeare and Phillips, on ninety-fathom dike, 67
Conybeare, Mr., on reptiles of the Lias, 347
Copper lode near Redruth, 612
Coprolite bed of Chloritic series, 283
—— beds of Red and Coralline crags, 177
Coprolites of fish, from the chalk, 281
Corals of the Carboniferous, 426
—— of the Devonian, 447
—— of the Mountain Limestone, 426
—— Miocene of United States, 211
—— *Neozoic type of*, 426
—— *Palæozoic type of*, 426
Coral Rag, fossils of the, 325
Coralline or White Crag, 178
—— percentage of extinct species in, 183
Corbula pisum, Hempstead beds, 228
Cordaites of the coal, 404
Corinth, corrosion of rocks by gases near, 586
Cornbrash or Forest Marble, 328
Cornstones, 444
Cornwall, granite veins in, 561
—— lodes in, 616
—— mass of granite in, 552
—— vertical sections of veins in mine, 609
Coseguina volcano, burying of organic remains by, 523
Couze, R., cutting through lava, 528
Crag, term defined, 173
—— of Antwerp, 185
—— fauna of, relation to that of present seas, 182
—— Norwich, 173
—— Coralline or White, 178
—— Red, 175
—— tables of marine testacea in, 183
—— deposits, climate of, 181
Crania attached to a sea-urchin, 25
—— *Parisiensis, White Chalk*, 277
Crassatella sulcata, Barton, 242
Craters and cones described, 494
—— Theory of Elevation, 495
Craven fault, 67
Creeps in coal-mines, 55
Cretaceous rocks of United States, 290
—— Period, error as to continuity of, 272
—— flora of the Upper, 285
—— volcanic rocks, 545
—— plutonic rocks, 572
—— Period, distinct mineral character of rocks in, 276
—— rocks, classification of, 265
—— strata, connection between Upper and Lower, 285
—— subdivisions, table of, 266
Crinoidea of Mountain limestone, 427
Croatia, Lower Miocene beds of, 226
Croll, Mr., on amount of subaërial denudation, 91
Cromer forest-bed, 172
—— formations succeeding the, 171
Crop out, term explained, 60
Crossopterygidæ, or fringe-finned fish, 439
Crowfoot, Mr., on shells of Aldeby beds, 173
Crust of the earth defined, 2
Crustaceans of Old Red Sandstone, 442
Cryptodon angulatum, London Clay, 250
Crystalline Limestone, 579
—— rocks defined, 8
—— schists, much alkali in the, 592
—— theory of cleavage, 592
Cuisse-Lamotte, Lits coquilliers of, 259
Cumberland, Upper Permian of, 376
Cup and Star corals, 426
Curved strata, 50–53
Cutch, salt-layers in the Runn of, 364
Cuvier, M., on divisions of Paris basin, 253
—— on Mammalia of Paris gypsum, 254
—— on Tertiary series, 118
Cyathocrinus caryocrinoides, 427
—— *planus*, 427
Cyathophyllum cæspitosum, 448
Cycads in Arctic Cretaceous Flora, 305
Cycas circinalis, 318
Cyclas (Sphærium) corneus, 30
Cyclopean Isles, tuff and clay in, 529
—— contorted strata in, 531
Cyclopteris Hibernica, Old Red, 437
Cyclostoma elegans, Loess, 32
Cylindrites acutus, Great Oolite, 332
Cypress swamps of the Mississippi, 387
Cyprides in the Weald Clay, 300
Cypridina serrato-striata, 447
Cyprina Morrisii, Thanet Sands, 253
Cypris in freshwater deposits, 33
—— *gibbosa, C. tuberculata, C. leguminella*, 310
—— *striato-punctata, C. fasciculata, C. granulata*, 311
—— *Purbeckensis, Cypris punctata*, 317
—— *spinigera, Weald Clay*, 300
Cyrena (Corbicella) fluminalis, 30
—— fluminalis in the Thames gravels, 139
—— *cuneiformis, Woolwich Clays*, 251
—— *semistriata, Hempstead beds*, 228
Cystideæ of Silurian rocks, 469
Cyrtoceras præcox, 482

DADOXYLON, fragment of coniferous wood, 422
Dana, on supposed legs of trilobite, 470
—— on volcanic minerals, 499
Danien, of French Cretaceous series, 266
Danish kitchen-middens, 123
Dapedius monilifer, Lias, 345
Darbishire on shells of Moel Tryfaen, 160
Dartmoor, post-carboniferous granite of, 573
Dartmoor Hill, lignites and clays of, 229
Darwin, Mr., on foliation and lamination, 596
—— on mammalia of South America, 138
—— on marine saurian, 349
—— on rise of part of South America, 49
—— on sinking of coral reefs, 49
—— on plutonic rocks of the Andes, 570

Darwin, Mr., on relationship of extinct to living types, 138
Dasyurus of Australia, 136
Dates of discovery of fossil vertebrata, 461
Daubeny, Dr., on basalt, 503
—— on decomposition of trachytic rocks, 586
Daubrée, on formation of zeolites, 521
—— on alkaline waters of Plombières, 585
Davidson, Mr., on Spiriferina, 342
David's Promontory, Cambrian of, 483
Davis, Mr. E., on fossils of Lingula Flags, 483
Dawkins, Mr. Boyd, on Hyæna spelæa, 135
—— on mammalia of Cromer Forest-bed, 170
—— on Triassic mammifer, 357
Dawson, Dr., on Devonian flora and insects, 451–453
—— on coal-plants, 417, 418, 420
—— on Eozoon Canadense, 491
—— on Nova Scotia coal-measures, 401
—— on Nova Scotia coal-plants, 418
—— on Pupa vetusta, 407
—— on rain-prints in coal, 410
—— on sporangia in coal, 405
—— on structure of sigillaria, 420
—— on structure of calamite, 418
—— reptiles and shells in Nova Scotia coal, 404
Dax, Tertiary beds of, 118
Deane, Dr., on footprints in Trias, 372
Debey, Dr., on flora and fauna of Aix, 286
Dechen, M. von, on Carboniferous Amphibia, 397
—— on organic remains of the brown coal, 510
—— on Cornish granite veins, 561
De la Beche, Sir H., on granite of Dartmoor, 582
—— on Carrara marble, 601
—— on mineral veins, 614
—— on Redruth copper-mine, 612
—— on trap rocks of New Red, 545
—— on saurians of the Lias, 349
—— on Welsh coal-measures, 388
Delesse, on action of water in metamorphism, 585
—— on porphyry, 506
—— on globular basalt, 511
Deltas, strata accumulated in, 4
Dendrerpeton in coal, 407
Denmark, three ages of stone in, 124
—— Faxoe chalk of, 269
Denudation defined, 73
—— subaërial, 74
—— littoral, 79
—— submarine, 81
—— average annual amount of subaërial, 90
—— of carboniferous strata, 387
—— counteracting upheaval, 83-92
—— a means of exposing crystalline rocks, 564
—— trap dykes cut off by, 518
—— and volcanic force antagonistic powers, 92
—— of surface by rivers, 91
Deposition, rate of, shown by fossils, 24
Deposits, mechanical and chemical, 37
Depth of the sea compared to height of land, 95
Derbyshire, veins in Mountain Limestone of, 610
Derivative shells of the Crag, 184
Desnoyers, M., on age of Faluns, 119
—— on Eocene fossil footprints, 255
Desor, M., on Celtic coins in lake-dwellings, 126
Deville, on contraction of granite, 615
Devonian Period, Upper, 446; Middle, 447; Lower, 450
—— fossils of the Eifel, 534
—— of Russia, 451
—— of United States and Canada, 451
—— insects of Canada, 453
—— strata, classification of, 445
Devonshire, cleavage of slate rocks in, 593
Diabase, 557
Diagonal or cross stratification, 18
Diagram of intrusive igneous rock, 521
—— of fossiliferous rocks, 114
—— of plutonic and sedimentary formations, 568
Diallage, 498, 501
—— rock, 558
Diastopora diluviana, Bath Oolite, 330
Diatomaceæ, figures of, 271
—— forming tripoli, 27
Diceras Lonsdalii, Neocomian, 294
Didelphys Azaræ, Recent, 334
Didymograpsus geminus, 475
—— *Murchisonii*, 472
Dike cutting through shale, Anglesea, 511
—— cutting through chalk, Antrim, 515
—— in Madeira and Arran, 513
—— ninety-fathom, 67
Dikes defined, 6
—— of Monte Somma, 526
—— in Palagonia, ground plan of, 531
—— volcanic or trap, 512–515
Dikelocephalus Minnesotensis, 489
Diluvium, origin of term, 115
Dimyary mollusca, term explained, 30
Dinornis Palapteryx of New Zealand, 138, 372
Dinosaurian of Oolite, 324
Dinotherium giganteum, 193
Diorite, 557
Diopside, 501
Dip and strike, terms explained, 57
Diplograpsus folium, Llandeilo Flags, 472
—— *pristis*, Llandeilo beds, 472
Dirt-bed of the Purbeck, 317
Disco Island Flora, 224
Dogger-bank described, 82, 176
Dolerite, a variety of basalt, 503
Dolgelly, Tremadoc beds of, 482
Dolomite defined, 14
Dolomitic conglomerate of Bristol, 361
Dore, Mont, Miocene strata of, 215
Downs, escarpments of North and South, 81
Downton Sandstone, 456
Dowson, Mr., on shells of Aldeby beds, 173
Drew, Mr., on Hastings Sands, 300
Drift of Ireland, 170
—— of Norfolk cliffs, 170
—— of North America, 162
—— of Scandinavia, 154

Drift of Bridlington, 169
—— carried by icebergs, 151
—— shells in Canada, 162
—— contorted strata in, 158
—— marine shells in Scotch, 156
Dryopithecus found at St. Gaudens, 196
Dudley Limestone, 462
—— Trilobite, 465
Duff, Mr. J., on Permian reptiles, 380
Dufrenoy, M., on granite of Pyrenees, 583
Dumont, Prof., on Belgian Lower Eocene, 265
Duncan, Dr., on Brockenhurst corals, 240
—— on Neozoic corals passing down to Devonian, 426
Dundry Hill, near Bristol, section of, 107
Dunker, Dr., on wealden of Germany, 304
Dura Den, yellow sandstone of, 436
Durdham Down, Triassic saurians of, 362
D'Urville, Capt., on Southern icebergs, 152

EARTH'S crust defined, 2
—— changes of level in the, 123
Earthquake in New Zealand, 149, 166
Echinoderms of Suffolk Crag, 181
Echinosphærites balticus, 470
Eden, Capt., on Coseguina eruption, 523
Ega, Lake, banks of dead insects on, 200
Egerton, Sir P., on fish of Headon series, 239
—— on fish of Trias, 372
—— on fish of the Permian, 379
—— on fish of Penarth beds, 355
Ehrenberg, Prof., on term Bryozoum, 178
—— on composition of tripoli, 27
—— on Silurian foraminifera, 476
—— on infusoria, 27
Eifel Limestone, 450
—— Lake-craters of, 531
—— Miocene volcanic rocks of, 540
—— Pliocene volcanos of the, 534
—— trass of the, 535
Elephas antiquus, molar of, 141
—— *meridionalis*, molar of, 141
—— *primigenius*, molar of, 141
Elevation craters, theory of, 495
Elie, Scotch drift of, 157
Elvans, term explained, 573
—— of Ireland and Cornwall, 617
Elytron of Buprestis? Stonesfield, 333
Emarginula clathrata, 332
Emmons, Prof., on jaws of Triassic quadruped, 373
Encrinites of Bradford, 330
Encrinus liliiformis, Muschelkalk, 369
Endogens, term explained, 287
Engihoul cave, human and animal remains in, 135
England and Wales, glaciation of, 159
English and French Eocene subdivisions, 233
Enstatite, 501
Eocene areas of Europe, map of, 233
—— foraminifera, 258
—— formations of France, 253-260
—— of England, 235
—— period, volcanic rocks of, 543
—— plutonic rocks of the, 569
—— metamorphic rocks of the, 600
Eocene of France, footprints in, 255
—— and Miocene, line between the, 213, 233
—— term defined, 120
—— of the United States, 262
Eozoon Canadense, oldest known fossil, 491
Eppelsheim, Miocene Gibbon of, 208
Epidote, 499
Equisetaceæ of the coal, 417
Equisetum arenaceum, 365
Equus caballus, tooth of, 142
Erratics, Alpine, 147
Erratic blocks, nature of, 145
—— of Greenland, 150
—— near Chichester, 161
—— in the Red Crag, 182
Errol, Scotch drift of, 157
Escarpments explained, 80
Eschara disticha, White Chalk, 279
Escharina oceani, White Chalk, 279
Esino, Triassic fauna of, 368
Estheria minuta, Trias, 358
—— *ovata, Richmond, Virginia*, 373
Etampes, fossil shells of, 214
Etheridge, Mr., on Atlantic mud, 271
—— Table of British Fossils by, 622
—— on Devonian series in Devon, 445
—— on Devonian fauna, 447, 450
—— on mollusca of Bracklesham, 244
—— on St. Cassian fossils, 367
—— on carboniferous mollusca, 428
Etna, built up since Newer Pliocene, 186
—— Pliocene lavas of, 529
—— shells of, 186
Ettingshausen on Sheppey Eocene fruit, 248
Eunomia radiata, Bath Oolite, 329
Eunotia bidens, Atlantic mud, 271
Euomphalus pentangulatus, 430
Euphotide, 558
Eurite, 557
Euritic porphyry of Norway, 562
Evans, Mr., on Archæopteryx, 324
Exogens, 287
Exogyra virgula, Kimmeridge Clay, 322
Extracrinus (Pentacrinus) Briareus, Lias, 344

FALCONER, Dr., on Miocene fauna of Siwâlik Hills, 209
—— on Brixham Cave flint knives, 135
—— on Microlestes, 356
—— on Purbeck mammalia, 312
Faluns of Loire, recent shells in, 192
—— of Touraine, 192
Farnham, phosphate of lime near, 283
Fascicularia aurantium, Coralline crag, 180
Faults in coal-measures of Coalbrook-Dale, 66
—— in mineral veins, 608
—— described, 64-70
—— often the result of repeated movements, 67
Fauna of the crag, its relation to that of our present seas, 182
—— of the Mountain Limestone, 425
—— of the Paris basin, 254
—— of the Permian, 378
—— marine of coal period, 425

Fauna, fossil of different ages tabulated, 622
Favosites cervicornis, Devonian, 448
—— *Gothlandica*, Silurian, 463
Faxoe, chalk of, 269
Felis tigris, tooth of, 143
Felsite and Felstone, 557
Felspar, varieties of, 498, 500, 554
Fenestella retiformis, *Permian*, 377
Ferns of the coal, 413
Fife, trap dike in, 545
Fish, fossil of the Carboniferous, 431
—— Eocene of Monte Bolca, 544
—— oldest known fossil fish, 461
—— number of living, 441
—— freshwater and marine, 34
—— Triassic of United States, 373
—— of the Upper Ludlow, 457
—— of the Old Red Sandstone, 438–441
—— of the Permian marl slate, 379, 380
—— of the brown coal, 541
—— of the Lias, 345
Fisherton, Greenland lemming in drift of, 139
Fissures, filled with metallic matter, 608
Fitton, Dr., on the Neocomian strata, 298
Flamborough Head, Speeton clay at, 295
Fleming, Dr., on Parka decipiens, 414
—— on trap dike in Fife, 546
Flemingites gracilis of coal, 405
Flint tools figured, 130
Flints in the chalk, 274
Flisk dike of Fife, 546
Flora of the Carboniferous, 413
—— Devonian, and Carboniferous, 452
—— of the Subapennines, 190
—— Lower Miocene of Switzerland, 218
—— Miocene of the Arctic Regions, 222
—— Older Pliocene of Italy, 190
—— of the Permian, 383
—— of the Upper Cretaceous, 285
—— Miocene of Switzerland, 197–206
—— of Vienna Basin, 208
—— Lower Miocene of Devonshire, 230
—— Fossil, of different ages tabulated, 622
—— of the Wealden, 305
Flower, Mr., on Halitherium, 178
Fluviatile beds underlying deep-sea strata, 252
Fluvio-marine or Norwich crag, 173
Flysch of the Alps, 262
—— plutonic rocks invading, 570
Folding of strata by lateral movements, 53
—— and denudation of Nova Scotia Carboniferous rocks, 410
Folds of parallel strata, arrangement and direction of, 70
Foliation of crystalline rocks, 596
Folkestone and Hythe beds, 292
Fontainebleau, Grès de, 213
Footprints in Potsdam sandstone, 489
—— *of reptiles in coal-measures*, 399
—— *fossil, in New Red*, 371
—— in Paris gypsum, 255
Foraminifera, Eocene, 258
—— forming chalk, 28
—— of Mountain Limestone, 432
—— of the chalk, 271
Forbes, Mr. David, on glass cavities in quartz, 555
—— on planes of foliation, 596
Forbes, Mr. David, on specific gravity of quartz, 499
—— on volcanic minerals, 499, 558
—— on age of gold veins, 619
Forbes, Professor E., on fossils of Bembridge beds, 235
—— on causes of reappearance of species, 295
—— on Cretaceous fossils of United States, 291
—— on Hempstead beds, 227
—— on Isle of Mull leaf-bed, 231
—— on Miocene lavas, 525
—— on shells of the crag, 181
—— on sphæronites, 471
—— on subdivisions of the Purbeck, 320
—— on term 'Pleistocene,' 122
—— on testacea of the Faluns, 193
—— on thickness of Upper Neocomian, 294
—— on two types of corals, 425
Foreland, sandstones of the, 416
Forest-bed at Cromer, 172
—— marble or cornbrash, 328
—— submerged, 79
—— fossil in coal, 391
—— fossil of Isle of Portland, 319
Forfarshire, Cephalaspis beds of, 412
—— contorted strata in, 158
—— section of curved strata in, 51
Formation, term defined, 4
Formations, Classification of Tertiary, 114
Fossil, term defined, 5
—— trees erect in coal, 401, 402
Fossiliferous groups, table of succession of, 108
Fossils, arrangement of, in strata, 23
—— a test of age of strata, 104
—— destruction of, in older formations, 116
—— found at great heights, 5
—— freshwater and marine, 28
—— obliterated by metamorphic action, 582, 605
—— rate of deposition indicated by, 23–27
—— recent and post-pliocene, 132–143
—— of the drift, 156, 170
—— of the Crags, 173–185
—— Upper Miocene, 194–212
—— Lower Miocene of Switzerland, 220
—— of the Hempstead Beds, 228
—— Eocene, 236
—— of the Barton Clay, 242
—— of the White Chalk, 277
—— of the Neocomian, 293–297
—— of the Oolite, 310–339
—— of the Stonesfield Slate, 333
—— of the Lias, 341
—— of the Trias, 357
—— of the Magnesian Limestone, 377
—— of the coal, 396
—— plants of the coal, 413–425
—— of the Mountain Limestone, 425
—— Fish of Old Red Sandstone, 438
—— of the London Clay, 247
—— of Moel Tryfaen, 160
—— Devonian, 446
—— Silurian, 456–479
—— Cambrian, 482–489
—— Laurentian, 491
Fournet, M., on metalliferous gneiss, 586

Fournet, M., on veins in granite, 613
Fox, Rev. D., on Isle of Wight Eocene fossils, 237
Fox, Mr. R., on lodes in Cornwall, 616
Fractures of strata, and faults, 61
Fragments, included, a test of age of plutonic rocks, 566
—— included, a test of age of strata, 106
—— a test of age in volcanic rocks, 524
France, Eocene formations of, 253–260
—— Lower Miocene of, 214
—— Upper Miocene of, 192
—— Reindeer Period of South of, 127
Freshfield, Mr., on absence of lakes in the Caucasus, 167
Freshwater strata, how distinguished from marine, 29–36
—— formation of Auvergne, 216
—— fossil plants and fish, 34
—— Liassic deposits, 350
Frostburg, carboniferous ferns of, 414
Fucoid sandstones of Sweden, 489
Fulgur canaliculatus, Maryland, 211
Fuller's earth, fossils of the, 336
Fundamental gneiss, 492
Fundy, Bay of, fossil trees exposed in cliffs at, 411
Fusilina cylindrica, 432
Fusion of quartz, 499
Fusus contrarius (*Trophon antiquum*), 177
—— *quadricostatus*, Maryland, 211

GABBRO, 558
Gaillonella ferruginea and G. distans, 27
Galapagos Islands, living marine saurian in, 349
Galeocerdo latidens, Bracklesham, 245
Galerites albogalerus, White Chalk, 277
Ganoids, the type of Old Red Sandstone fish, 439
—— of the Wealden, 301
—— of the Trias, 373
Gaps in the sequence of fossil remains, 116
Garnet, 499
Gases, corrosion of rocks by, 586
Gastornis Parisiensis in Plastic clay, 260
Gaudin on Lower Miocene of Switzerland, 219
—— on Pliocene flora of Italy, 190
—— on Proteaceæ in Eocene, 246
Gaudry, M., on Miocene vertebrata of Vaucluse, 196
—— Pikermi, 209
—— on divisions of the Miocene, 192
Gault, thickness and fossils of, 281
Geikie, Mr. A., on Ayrshire Permian trap rocks, 546
—— on subaërial denudation, 92
—— on ice erosion of lake basins, 167
—— on Pentland Old Red volcanic rocks, 549
—— on Silurian metamorphic rocks, 604
—— on syenite of Mull, 569
—— on second striation of boulder-clay, 158
—— on Tertiary lavas, 525
—— on foliation, 596
Geinitz, M., on Permian flora, 383
Gemunder Maar, volcanic rocks of, 534
Geneva, Lower Miocene of, 219
Geographical relationship of animals, 138
Geology defined, 1
Gergovia, tuffs and associated lacustrine strata of, 542
Germany, Lower Miocene of, 225
—— Triassic fauna of, 364
—— Permian rocks of, 382
Gers, Upper Miocene of, 196
Gervillia anceps, Neocomian, 294
—— *socialis, Muschelkalk*, 369
Gesner, Dr., on carboniferous footprints, 407
Giant's Causeway basalt, 6
—— age of, 231
—— laterite of the, 509
Gibbon of Gers and Eppelsheim, 196, 208
Gibbes, Dr., on Alabama Zeuglodon, 263
Girgenti, Newer Pliocene of, 188
Glacial drift, distribution and nature of, 144
—— formations of Pleistocene age, 144
—— drift of Ireland, 170
—— formations of Pliocene age, 169
—— erosion of lake-basins, 163–168
—— epoch, changes of level in the, 96
Glaciation of Russia and Scandinavia, 154
—— of Scotland, 155
—— of Wales and England, 159
—— of North America, 162
Glaciers, transporting and abrading power of, 146
Glasgow, buried canoes near, 123
Glass cavities in quartz, 555
Glauconie grossière, 258
Glen Tilt, junction of granite and schist at, 559
Globiform pitchstone, 512
Globigerina bulloides, 271
Globular structure of volcanic rocks, 509
Glyptostrobus Europaeus, Œningen, 205
Gneiss, granite veins traversing, 560
—— defined and figured, 577
—— fundamental, of Scotland, 492
Gold mines of Australia and Chili, 619
—— veins of Russia, 618
—— of California, of age of alluvium, 619
—— origin of, 619
—— cause of rich cappings of, 620
Goldenberg, Professor, on Saarbrück coal insects, 397
Goldfuss, Professor, on reptiles in coal, 397
Goniatites crenistria, 431
—— *Listeri*, coal measures, 396
Göppert, on American forms in Swiss Miocene flora, 205
—— on petrifaction, 45
—— on plants of coal measures, 389
Gorgonia infundibuliformis, Permian, 377
Graham's Island, forming ashy conglomerate, 544
Grampians, Old Red conglomerates of, 50
—— trap rocks of the, 548
—— former glaciers in the, 155
Grand Canary, Upper Miocene, shelly tuffs of, 537
—— denudation in the, 538
Granite, composition of, 552
—— graphic and columnar, 553

Granite, how far connected with volcanic rocks, 558
—— hornblendic and talcose, 557
—— hydrothermal action in formation of, 555
—— metamorphosing fossiliferous strata, 581
—— porphyritic, 556
—— oldest, 575
—— passage of, into trap, 558
—— veins, 559, 560
Granton, monocotyledon found in coal at 424
Graptolites of Bala beds, 471
Graptolites Murchisonii, Llandeilo flags, 472
Graptolithus priodon, Silurian, 465
Grays, Essex, pachyderms found at, 139
Great (or Bath) Oolite, 328
Greece, Upper Miocene formations of, 208
Greenland, continental ice of, 150
—— gradual sinking of, 49, 79
—— Miocene flora of, 223
Greensand, use of term, 265
—— Upper, or Chloritic series, 282
Greenstone, 504
Grés de Beauchamp, Paris basin, 257
Grés de Fontainebleau, age of the, 213
Grés bigarré, 364
Grey sandstone of Upper Ludlow, 457
Griffiths, Sir R., on yellow sandstone of Ireland, 436
Gristhorpe, Oolitic ferns of, 336
Grit defined, 12
Groups, older, rise highest above the sea, 116
—— why the newest to be studied first, 117
Gryllacris lithanthraca, coal, 397
Gryphite Limestone, 341
Gryphæa coated with *serpulæ*, 24
—— *columba*, *Chloritic Sand*, 283
—— *convexa*, *chalk*, 278
—— *incurva* (*G. arcuata*), 30, 341
—— *virgula*, *Kimmeridge clay*, 322
Guadaloupe, glass cavities in quartz of, 555
Gulf-Stream, probable abrading power of, 82
Gümbel, M., on Rhætic beds, 354
Gunn, Mrs., on potstones in the chalk, 274
Günther on Ceratodus, 441
Gutbier, Colonel, on Permian flora, 383
Gymnogens, term explained, 287
Gypsum and gypseous marl defined, 14
Gypseous marls of Auvergne, 216
—— series of Montmartre, 253
Gyrogonites of the Wealden, 305
Gyrolepis tenuistriatus, Rhætic beds, 355

HAIME, Mr., on palæozoic corals, 426
Hakea silicina and *Hakea saligna*, Œningen, 204
Halitherium in coprolite bed, 178
Hall, Captain Basil, on Cyclopean Isles, 530
—— Sir James, on curved strata, 53
—— Mr. J., on Appalachian palæozoic rocks, 87
Hallstadt and St. Cassian beds, 365
Halysites catenularis, Silurian, 463
Hamilton, Sir W., on eruption of Vesuvius, 1779, 526
Hamites spiniger, *Gault*, 284
Hancock, Mr., on Protorosaurus in Permian, 380
Harding, Dr., on carboniferous footprints, 407
Harkness, Professor, on Silurian metamorphic rocks, 604
—— on Penrith sandstone, 381
Harlech grits, fossils of the, 485
Harris, Major, on the Salt Lakes, 364
Harpactor maculipes, Œningen, 206
Harpe, M. de la, on Bournemouth Eocene flora, 246
Hartung, Mr., cited, 495, 532, 537
—— on shells of Azores, 539
Hartz mountains, mineral veins of, 610
—— Bunter Sandstein of, 370
Hastings Sands, subdivisions of the, 300
Hautes-Alpes, granite of the, 572
Haüy on isomorphism, 561
Headon series, fossils of the, 238
Heat, powerful in consolidating rocks, 42
—— rocks upraised and folded by, 69
—— internal, caused by transfer of sediment, 94
Hébert, M., on age of Sables de Bracheux, 260
—— on Gastornis Parisiensis, 260
—— comparison of Sables Moyens and Barton shells, 242
—— on pisolitic limestone, 268
Hebrides, dikes in the, 514
—— hornblendic gneiss of the, 88
—— Eocene volcanic rocks of the, 543
Heer, Professor, on American genera in Swiss Miocene, 222
—— on age of Madeira leaf-bed, 533
—— on Arctic Cretaceous flora, 305
—— on Arctic Miocene flora, 222
—— on Bear Island flora, 437
—— on Bovey Tracey Miocene flora, 230
—— on fossil plants of Switzerland, 197, 199, 206, 219, 220
—— on Lower Miocene plants of Mull, 231
—— on Monte Bolca Eocene plants, 246, 544
—— on Proteas of Lower Miocene, 220
—— on plants of Hempstead beds, 229
—— on plants of coal-field, Virginia, 372
—— on Swiss Miocene insects, 205
—— on supposed Proteaceæ of Œningen beds, 205
—— on Superga fossil plants, 227
Heidelberg, varieties of granite near, 560
Heligoland, Lower Neocomian of, 297
Heliolites porosa, Devonian, 447
Helix hispida (*plebeia*), 132
—— *labyrinthica*, *Headon*, 238
—— *occlusa*, *Bembridge*, 236
—— *Turonensis*, faluns, 32
Hemicidaris Purbeckensis, *Purbeck*, 310
Hemipneustes radiatus, *Chalk*, 267
Hemitelites Brownii, *Inf. Oolite*, 337
Hempstead beds, subdivisions of the, 227
Henry, on absorption of carbonic acid gas in water, 586

Henslow, Professor, on dike in Anglesea, 514
—— on Red Crag coprolite bed, 177
—— on Portland dirt-bed, 319
Hermsdorf, Rupelian clay of, 225
Hertfordshire pudding-stone, 39
—— to France, Cretaceous section, 270
Herschel, Sir J., on slaty cleavage, 592
Heterocercal tail of fish, 379
Hicks, Dr., on fossils of Arenig beds, 471
—— on fossils of Harlech grits, 486
—— on Menevian beds, 484
—— on Tremadoc beds, 482
Highland metamorphic rocks, 603
Hils conglomerate, 297
Himalaya, shells 18,000 feet high in, 5
—— Upper Miocene of, 209
Hippopodium ponderosum, Lias, 342
Hippopotamus, tooth of, 142
—— in Thames gravels, 139
Hippurite Limestone, 288
Hippurites organisans, chalk, 290
Hitchcock, Professor, on Trias footprints, 371
Histioderma hibernica, 185
Holoptychius nobilissimus, scale of, and restoration of fish, 438
Homalonotus Delphinocephalus, 465
—— *armatus*, Devonian, 450
Homfray, Mr., on fossils of Tremadoc beds, 482
Homocercal tail of fish, 379
Hooghley River, analysis of water, 45
Hooker, Dr., on coniferæ, 423
—— on structure of sigillaria, 420
—— on sporangia of Silurian plant, 457
—— on coal-plants, 417
Hordwell Cliff, Hyænodon in Eocene of, 218
—— Helix labyrinthica in, 239
—— Barton and Headon beds of, 241
Horizontality of strata, 16
Horizontal strata, upheaval of, 48
Hornblende, 498, 501
Hornblende-schist, 578
Hornblendic granite, 557
Hörnes, Dr., on fossil mollusca of Vienna basin, 207
Horstead, potstones at, 274
Hourglass illustrating the destruction and renovation of land, 95
Howse, Mr., on Protorosaurus, 380
Hubbard, Professor, on granite of White Mountains, 566
Hudson River Group, fossils of the, 479
Hughes, Professor, cited, 149, 286, 445, 595
—— on slaty cleavage, 590
Hull, Mr. E., on breccias in Permian, 381
—— on carboniferous of Lancashire, 387
—— on carboniferous rocks of north of England, 88
—— on faults in Lancashire coal-field, 69
—— on anticlinals and synclinals, Lancashire, 62
—— on thickness of the Upper Trias, 357
—— on thickness of Permian, 376
—— on three lines of flexure since the coal in Lancashire, 71
Human works of Recent Period, 124
—— in cavern deposits, 133
Humboldt, on mineral character of rocks, 604
—— on mean height of American continent, 92
Humphreys and Abbot on Mississippi denudation, 91
Hungary, trachyte of, 559
Hunt Sterry, on action of water in metamorphism, 585
Huronian series, thickness of the, 489
Huxley, Professor, on Atlantic chalk-mud, 270
—— on affinity between reptiles and birds, 324
—— on fish of Old Red Sandstone, 439–442
—— on Pteraspis, 462
—— on Hyperodapedon, 358
—— on Permian reptiles, 380
—— on spores and sporangia of coal, 405
Hyæna den of Kirkdale cave, 135
Hyæna spelæa, tooth of, 143
Hybodus plicatilis, Rhætic beds, 355
reticulatus, Lias, 346
Hydrothermal action producing metamorphism, 581
—— in formation of granite, 555
Hymenocaris vermicauda, 483
Hyperodapedon Gordoni, Trias, 358
Hypersthene, 498, 501
—— rock, 504
—— rocks of Skye, 490
Hypogene rocks, uniformity of mineral character in, 604
—— rocks, term defined, 10
Hypsiprymnus Gaimardi, molar of recent, 313
—— of Australia, 136
Hythe, Neocomian beds of, 292

ICEBERGS, drift carried by, 151
—— stranded in Baffin's Bay, 152
Ice-erosion of lake-basins considered, 163
—— abrading power of, 146
—— continental of Greenland, 150
Ice-borne erratics at Chichester, 161
Iceland, glass cavities in quartz of, 555
—— flow of lava in, 523
Ichthyornis dispar of Kansas, 291
Ichthyosaurus communis, Lias, 348
Ichthyodorulite of the Lias, 346
Idocrase, 499
Iguanodon Mantelli, Weald Clay, 299
Ilfracombe Group of Devon, 446
—— section of slate rocks near, 594
Imperfection of the record, 115
Inclined strata, 50
India, Miocene formations of, 209
Inferior Oolite, thickness and fossils of, 336
Infusoria in tripoli, 27
Inland sea-cliffs, 80
Inoceramus Lamarckii, White Chalk, 278
Insect in coal, 396, 408
—— beds of the Lias, 350
—— *wing of neuropterous*, 350
Insects, Devonian, of Canada, 453
—— in European coal, 396
—— Miocene, of Croatia, 226
—— Upper Miocene, at Œningen, 205

Insects, causes of fossilisation of, 200
Intrusion, a test of age of plutonic rocks, 566
—— a test of age of volcanic rocks, 517
Inundation mud of rivers, 130
Ireland, glacial drift of, 170
—— yellow sandstone of, 436
—— to the Crimea, chalk from, 270
—— carboniferous strata of, 387
Iron pyrites, 499
—— weapons of Swiss lake-dwellings, 125
Isle of Bourbon, lava current of the, 567
—— Cyclops, view of, 530
—— Wight, Hempstead beds, 227
—— Wight, Eocene beds, 238, 251
—— Mull, Miocene leaf-bed of, 230
—— Mull volcanic rocks, 539
Isastræa oblonga, Portland Sand, 322
Isomorphism, theory of, 501
Italy, Lower Miocene of, 227
—— Older Pliocene volcanos of, 533
—— Pliocene of, 189
—— Older Pliocene flora of, 190
—— Upper Miocene strata of, 208

JAEGER on Mastodonsaurus, 365
Jamieson, Mr. T. F., on Scotch glacial drift, 155
Java, volcanic explosions in, 495
Jaws of mammalia in Purbeck, 311
Jeffreys, Mr. Gwyn, on Atlantic mud, 271
—— on recent deep-sea dredging, 183
—— on living Pentacrinus, 345
Johnson, Mr., on Madeira fossils, 537
Jointed structure of metamorphic rocks, 591
Jones, Dr. Rupert, on Eozoon Canadense, 491
Jorullo, lava stream of, 567
Judd, Mr., on Speeton clay, 295–297
—— on Tithonian, 292
—— on volcanic rocks of the Hebrides, 513
—— on Tertiary plutonic rocks, 569
—— on Scotch intrusive granite, 582
Jukes, Mr., on Tarannon shales, 466
Jura, erratic blocks on the, 147
—— structure of the, 59
—— on Post-tertiary lavas, 525

KANGAROO, jaws of, 136, 137
Kansas, Cretaceous birds of, 291
Kaolin, composition of, 12
Käsegrotte, Bertrich Baden, Basaltic pillars of, 511
Kaup, Professor, on footprints o the Trias, 360
Keilhau, Professor, on granite veins, 562
—— on planes of foliation, 596
—— on Silurian granite of Norway, 574
—— on protrusion of granite, 581
Keller, Dr. F., on lake-dwellings, 125
Kelloway Rock, percentage of Oxford clay fossils in, 328
—— consolidation of, 38
Keuper of Germany, 365
—— or Upper Trias of England, 357
Kentish Rag, 293
Killas, altered by granite in Cornwall, 582
Kilkenny, fossil plants of, 436
Kiltorkan, yellow sandstone of, with Anodonta, 436
Kinahan, Dr., on Cambrian annelids, 485
Kimmeridge clay, 323
King-crab of China, 443
King, Dr., on reptile footprints in coal, 400
—— Mr., on Permian fossils, 379
Kirkdale cave, hyæna's den of, 135
Kitchen-middens of Denmark, 123
Kleyn Spawen beds, 224
Koessen beds, 354
Könen, Baron von, on Brockenhurst shells, 240
Koninck, M. de, on Mountain Limestone fish, 431
—— on shells of Mayence basin, 225
Koninckia Leonhardi, Hallstadt, 366
Kupfer schiefer of Germany, 382
Kyson, mammalian remains at, 250

LABRADOR rock, 504
—— series, 490
Labradorite, 498, 500
Labyrinthodon Jaegeri, tooth of, 359
Labyrinthodonts of coal, 397
La Fere, Tertiary mammifer at, 260
Lago Maggiore, formation of the, 165
Lake-craters of the Eifel, 534
Lake districts, southern limits of the, 161
Lake dwellings, scarcity of human remains in, 126
—— in Switzerland, 125
Lakes, deposits in, 3
—— connection of with glacial action, 163–168
Lamarck on bivalve mollusca, 30
Lamination of clay slate, 597
Lamna elegans, Bracklesham, 245
Lancashire, vast thickness of rocks without corresponding altitude in, 88
—— section of carboniferous rocks. 62
Lancerote, veins in crater of, 612
Land, balance of dry, how preserved, 93, 95
—— extent of, in Permian, 382
—— has been raised, not the sea lowered, 47
—— mean height of, above the sea, 92
—— rise of, in Sweden, 49
—— rise and fall of, affecting denudation 78
Landenian of Belgium, 265
Land-ice, action of, in Greenland, 150
Land's End, columnar granite at, 552
—— porphyritic granite at, 556
La Roche, recent deposits in estuary of, 15
Lartet, M., on mammalia of Faluns, 195
—— on Gastornis Parisiensis, 260
—— on reindeer period, 126
Lastræa stiriaca, Monod, 221
Latera lcompression causing curved strata 53, 86
—— moraines, 147
Laterite of Giant's Causeway, 508
Laurentian gneiss of Scotland, 492
—— Group, Upper and Lower, 490
—— thickness of, in Canada, 90
—— metamorphic rocks, 602
—— volcanic rocks 550

Lava, 507
—— consolidating on slopes, 496
—— currents of Auvergne, 541
—— streams, effect of, 6
—— of La Coupe d'Aysac, 510
—— of Jorullo, 567
Lead veins, age of, 618
Leaf-bed of Madeira, 532
—— Isle of Mull Miocene, 230
Leda amygdaloides, London Clay, 249
—— *Deshayesiana* (*Nucula Deshayesiana*), 224
Leda lanceolata (*L. oblonga*), Scotch drift, 156
—— *truncata*, Scotch drift, 157
Lee, Mr. J. E., on Pteraspis of Lower Ludlow, 462
Leidy, Dr., on fossil quadrupeds of Nebraska, 232
Leintwardine, Pteraspis found at, 462
Leperditia inflata, coal-measures, 396
Lepidodendron Griffithsii, 437
—— *corrugatum*, carboniferous, 410
—— *Sternbergii*, coal-measures, 416
Lepidolite, 498, 501
Lepidostrobus ornatus, coal, 417
Lepidotus gigas, Lias, 345
—— *Mantelli, Wealden*, 301
Leptæna depressa, Wenlock, 461
—— *Moorei, Lias*, 342
Leucite, 498
Level of surface altered by change of subterranean heat, 96
Lewis, hornblendic gneiss of, 603
Lias, calcareous nodules in, 40
—— fishes of the, 345
—— fossils of the, 341
—— and Oolite, origin of the, 351
—— reptiles of the, 347
—— insects of the, 350
—— plants of the, 351
—— plutonic rocks of the, 572
—— subdivisions of the, 340
—— volcanic rocks of the, 545
Liebig, on conversion of coal into anthracite, 394
—— on origin of stalactite, 134
Liége, limestone caverns at, 134
Lightbody, Mr., on Ludlow shales, 459
Lignite, conversion of, into coal, 394
Lignites of Bovey Tracey, 229
Lima giganteum, 341
—— *Hoperi, Chalk*, 284
—— *spinosa, White Chalk*, 277
Limagne d'Auvergne, Lower Miocene mammalia of the, 217
Limburg beds, 225
Lime, scarcity of, in metamorphic rocks, 606
—— in solution, source of, 45
Limestone, block of striated, 146
Limestone formed of corals and shells, 23
—— brecciated, 377
—— of chemical and organic origin, 38
—— Hippurite, 288
—— Magnesian, 14, 376
—— metamorphic or crystalline, 579
—— Mountain, and its fossils, 425
—— striated, 146
Limnæa caudata, 239
—— *fusiformis*, 236
Limnæa longiscata, 31
Lingula beds, volcanic tuffs of the, 550
—— flags, fossils of the, 483
Lingula Credneri, Permian, 378
—— *Dumortieri*, Crag. 181
—— *Lewisii*, Ludlow, 459
Lingulella Davisii, 483
Lipari Isles, tufas in, 586
Liquidambar europæum, 191
Lithrostrotion basaltiforme, Carboniferous, 427
Lits coquilliers, 259
Littoral denudation defined, 79
Lituites giganteus, Ludlow, 460
Llanberis slates, 485
Llandeilo Flags, fossils of the, 472
Llandeilo formation, thickness of the, 473
—— Lower, 474
Llandovery Group, classification of the, 466
—— Rocks, thickness of the Lower, 468
Loam defined, 14, 130
Loch Assynt, unconformable Palæozoic strata of, 89
Locle, Proteaceous plants of, 203
Lodes, shells and pebbles in, 614
—— *See* Mineral Veins
Loess or fluviatile loam described, 131
—— fossil shells of the, 132
Logan, Sir W., on Eozoon Canadense, 491
—— on Gaspé sandstones, 451
—— on Huronian and Laurentian, 489
—— on Potsdam sandstone, 489
—— on stigmaria in underclays, 381
—— on thickness of Nova Scotia coal, 401
—— on thickness of Laurentian in Canada, 90
Loire, faluns of the, 192
London Clay, fossils of the, 247, 249
Longevity, relative, of mammalia and testacea, 140
Longmynd Group, fauna of the, 485
Lonsdale, Mr., on Devonian fossils, 445
—— on Stonesfield slate, 332
—— on United States Miocene corals, 211
—— on corals of the Faluns, 194
—— on Madeira shells, 537
Lonsdaleia floriformis, Carboniferous, 427
Lowe, Rev. R. T., on Mogador shells, 537
Lubbock, Sir J., on the two stone-periods, 126
Lucina serrata, Bracklesham, 245
Ludlow formation, Upper, 456; Lower, 458
—— bone-bed of the Upper, 456
Lulworth Cove, dirt-bed of, 320
Lycett, Mr., on Great Oolite fossils, 331
Lycopodiaceæ of coal, 415
Lycopodium densum, living species, 416
Lym-fiord, mingled freshwater and marine strata of, 35
Lynton Group of Devon, 446, 450

MACLAREN, Mr., on Pentland Hills, volcanic rocks, 549
Macclesfield, marine shells 1,200 feet high at, 161, 166
McClintock, Sir R., on Atlantic mud, 271
McCulloch, Dr., on Aberdeenshire granite, 558

McCulloch, Dr., on consolidation of Skye sandstone, 40
—— on trap, 518
McCulloch, Mr. J., on Eozoon Canadense, 491
Macropus atlas, lower jaw of, 136
—— *major* (living), lower jaw of, 137
Madeira, beds of laterite in, 509
—— dike in valley in, 513
—— Pliocene leaf-bed and shells in lavas of, 532
—— Miocene volcanic rocks of, 536
—— wind removing scoriæ in, 74
Maestricht beds and their fossils, 266
Maffiotte, Don Pedro, cited, 538
Magas pumila, White Chalk, 277
Magnesian Limestone, concretions in, 41
—— Limestone, defined, 14
—— and marl-slate, 376
—— fish-scales of, 380
Magnetite, 499
Maidstone, Upper Cretaceous fossils of, 280, 298
Malacolite, 501
Malaise, Professor, on Engihoul cave, 135
Malvern Hills, Wenlock limestone of, 163
Mammalia, anterior to Paris gypsum, table of, 315
—— extinct, coeval with man, 131, 139
—— fossil, of Middle Purbeck, 311
—— fossil, in Pliocene in Val d'Arno, 190
—— fossil, in the Crag, 172, 178
—— fossil, of Vienna basin, 207
—— low grade of, in early strata, 374
—— of Paris basin, 254
—— of the Limagne d'Auvergne, 217
—— of Siwâlik Hills, 209
—— of the Stonesfield slate, 332
—— *teeth of Postpliocene*, 142
—— and testacea, comparative longevity of, 140
Mammifer of the Trias, 373
Mammoth, rude carving of, in Perigord cave, 127
—— in Scotch till, 155
—— *See* Elephas primigenius
Man, antiquity of, 129
Manfredi on amount of subaërial denudation, 90
Mantell, Dr., on iguanodon of Wealden, 299, 301
—— on Oxford Clay belemnites, 327
—— on Wealden fossils, 297
Mantellia nidiformis, Purbeck, 318
Map of Chalk formation in France, 289
—— of Eocene tertiary basins, 233
—— of Hallstadt and St. Cassian beds, 366
Marble defined, 13
—— of Carrara, metamorphic, 601
Marcou, M., on age of Wealden beds, 304
Margaric acid, 592
Margarite, 498
Marine fauna of the Carboniferous, 425
—— beds underlying the London clay, 252
—— and brackish-water strata in coal, 395
—— strata, how distinguished from freshwater, 29–36
—— strata, causes of elevation of, 47
—— and freshwater strata, alternations of, 49
Marnes à gryphées virgules, 323
—— irisées, 364
Marl from Lake Superior, 40
—— and marl-slate defined, 14
—— red, green, and white of Auvergne, 216
—— slate of Middle Permian, 376
Marsh, Prof., on cretaceous birds of Kansas, 291
Marsupials, extinct, of Australia, 136
Marsupites Milleri, White Chalk, 277
Mastodon arvernensis, molar of, Norwich crag, 174
—— giganteus in United States after the drift, 163
Massachusetts, plumbago of, 584
Mauch Chunk, coal of, 392
Mayence basin tertiaries, 225
Mayer, M. Karl, on Madeira fossil shells, 537
May-Hill Sandstone, 466
Mechanical and chemical deposits, 37
—— theory of cleavage, 593
Medial moraines, 147
Mediterranean, one zoological province, 103
—— volcanic island formed in the, 83
Megalodon cucullatus, Devonian, 419
Melania inquinata (*Cerithium melanoides*), 251
—— *turritissima, Bembridge*, 236
Melanopsis buccinoidea, 31
Melaphyre, a variety of basalt, 504
Menevian beds and their fossils, 484
Mergel-schiefer of Germany, 382
Mesozoic, term explained, 100
—— and Cainozoic periods, gap between the, 264
—— and Palæozoic rocks, limits of the, 375
Metals, relative age of different, 616
Metalliferous veins, origin of, 608
Metamorphic limestone, 579
—— strata, origin of, 580
—— theory, objections to, considered, 587
—— rocks defined, 8
—— —— 577
—— —— cleavage of, 589
—— —— scarcity of lime in, 606
—— —— ages of, 599
—— —— order of succession of, 604
—— —— uniformity of mineral character in, 604
Metamorphism, hydrothermal action producing, 584
Metamorphosis of trilobites, 470
Meteorites, minerals in, 500
Mexico, Gulf of, terrestrial remains washed into, 105
Meudon, Pisolitic Limestone of, 268
—— Gastornis Parisiensis of, 260
Meyer, M. H. von, on reptiles in coal, 397
—— on Belodon, 357
—— on Wealden of Germany, 304
Miascite, 557
Mica and its varieties, 498, 501
—— how deposited, 16
—— schist or micaceous schist, 579
Micaceous sandstone, origin of, 12
Micraster cor-anguinum, 277
Micraster with serpula attached, 25

Microconchus carbonarius, coal-measures, 396
Microlestes antiquus, *Upper Trias*, 356
Migrations of quadrupeds, 139
Miliolite limestone, 258
Miller, Hugh, on Old Red Sandstone fish, 438
—— on salt lakes, 364
Millstone-grit, 386
Milne-Edwards, Mr., on Miocene subdivisions, 192
—— on Palæozoic corals, 425
Minchinhampton, Great Oolite of, 331
Mineral composition of strata, 11
—— a test of age of volcanic rocks, 523
—— a test of age of plutonic rocks, 566
—— a test of age of strata, 101
—— character of cretaceous rocks, 276
—— character of hypogene rocks, 604
—— springs of Auvergne, 606
—— veins, different kinds of, 607
—— —— formed in fissures, 608
—— —— rocks altered by, 559
—— —— successive formation of, 611
—— —— swelling and contraction of, 614
—— —— relative age of, 616
—— —— pebbles in, 614
—— —— chemical deposits in, 615
—— —— question of origin of, 620
Minerals in meteorites, 500
—— table of the most abundant in hypogene rocks, 484
Mineralisation of organic remains, 42
Minudie, anticlinal axis of coal-measures at, 411
Miocene of Bordeaux and South of France, 195
—— and Eocene, line between the, 213, 233
—— Arctic Flora, 222, 224
—— Lower, of England, 227
—— Lower, of Germany and Croatia, 225, 226
—— Lower, of Central France, 214
—— Lower, of Italy, 227
—— Lower, of Nebraska, United States, 232
—— term defined, 120
Miocene, Upper, of the Bolderberg, 206
—— Upper, of France, 195
—— Upper, of Italy, 208
—— Upper, of Greece, 208
—— Upper, of India, 209
—— Upper, of Œningen, 197
—— Upper, of Vienna basin, 207
—— volcanic rocks, 536–543
Mitscherlich, on isomorphism, 503
Mitchell, Mr., on Aralia fruit in Alum Bay Eocene, 246
—— Sir T., on Wellington caves, 136
—— Rev. Hugh, on Pteraspis, 427
Mitra Scabra, Barton clay, 242
Mississippi, sediment of, used as a test of denudation by rivers, 91
—— swamps of the, 393
—— valley, deposition and denudation in the, 79
Mobile, Alabama, Cyrena found at, 252
Model, supposed, of the capacity of the ocean, 95
Modiola acuminata, *Permian*, 377
Moel Tryfaen, shells found at, 160
Möhs on isomorphism, 501
Molasse, Lower, of Switzerland, 218
—— Middle, or Marine, of Switzerland, 206
—— Upper Freshwater, of Switzerland, 199
—— term explained, 199
Mollusca. *See* Shells
—— longevity of species of, 140
—— of Hallstadt beds, 367
—— value of, in classification, 119
—— of the Carboniferous, 428
Monitor of Thuringia, 380, 461
Monoclinic felspars, 500
Monocotyledon in coal-measures, 424
Monod, flora of the Lower Molasse at, 219
Monomyary mollusca, term explained, 30
Mons, unconformable strata near, 72
Mont Dore, Auvergne, extinct volcanos of, 215
—— age of volcano of, 541
Monte Bolca, fossil fish of, 544
—— Calvo, cross stratification, 20
—— Mario, age of volcanic deposits of, 533
—— Nuovo, formed 1538, 525
Montmartre, gypseous series of, 253
Montmorency, fossil footprints at, 255
Monts Dome, extinct volcanos, 495
Moore, Mr. C., on lead-veins, 611
—— on Rhætic beds, 354
—— on Upper Trias quadrupeds, 357
Moraines described, 147
Morea, cretaceous volcanic rocks of, 545
—— inland sea-cliffs of the, 80
Morris, Prof., on spores in coal, 405
Morthoe, Devonian strata at, 446
Mortillet, M. de, on ice-erosion of lake-basins, 164
Morton, Dr., on age of American cretaceous rocks, 291
Mosasaurus Camperi, *chalk*, 267
Mountain Limestone, fossils of the, 425–432
Mudstone of Upper Ludlow, 457
Mull, Isle of, leaf-bed, 230
Münster, Count, on fossils of Solenhofen, 323
Murchisonia gracilis, 479
Murchison, Sir R., on area of the Swiss Molasse, 199
—— on ball-stones of Wenlock Limestone, 463
—— on brackish-water strata in coal, 395
—— on Devonian series, 434, 445
—— on Devonian ichthyolites, 450
—— on Eocene igneous rocks, 262
—— on formation of gneiss, 609
—— on Llandovery beds, 466
—— on Laurentian gneiss of Scotland, 492
—— on metamorphic rocks of North Highlands, 603
—— on Monte Bolca fish-beds, 544
—— on name Permian, 375
—— on Old Red Sandstone, 434, 438, 444
—— on Palæozoic strata, Queenaig, 89, 90
—— on Permian of Russia, 383
—— on Silurian, 457, 459, 461, 465, 468
—— on Tertiary volcanic rocks of Italy, 584
—— on thickness of chalk in Russia, 270
—— on thickness of the Trias, 358
Murex vaginatus, 186
Muscovite, or common Mica, 498, 501

Muschelkalk, fossils of the, 368
Musk-sheep, fossil, in Thames valley, 139
Myliobates Edwardsi, Bracklesham, 244
Mytilus septifer, Permian, 377

NAPLES, volcanic rocks of, 525
—— escape of carbonic acid near, 606
Natica clausa, Scotch drift, 156
—— *helicoides*, Chillesford beds, 173
Natrolite, 499
Nautilus centralis, London Clay, 249
—— *Danicus, Faroe Chalk*, 269
—— *plicatus, Hythe beds*, 293
—— *truncatus, Lias*, 343
—— *ziczac (Aturia ziczac)*, 249
Nebraska, Miocene strata of, 232
Necker, M., on 'underlying' igneous rocks, 563
—— on dikes in Vesuvius, 526
Neocomian, Upper, 292
—— Middle, 296
—— Lower, 297
—— use of the term, 265
Neolithic era, 125
Neozoic type of corals, 426
Nepheline, 498
Neptune's Cups of Sumatra, 275
Nerinæa Goodhallii, Coral Rag, 326
Nerinæan limestone, 326
Nerita conoidea (N. Schmidelliana), 259
—— *costulata, Great Oolite*, 332
—— *granulosa*, 32
Neritina concava, Headon, 239
—— *globulus*, 32
Neuchatel, coins and iron tools in lake of, 125
Newberry, Mr., on flora of American cretaceous rocks, 291
Newcastle, coal-field, faults in, 67
—— coal-pipes in mines of, 390
Newfoundland bank described, 83
New Jersey, cretaceous rocks of, 290
—— mastodon in, 163
New Madrid, 'Sunk Country' in, 393
New Red Sandstone of Connecticut Valley, 371
—— trappean rocks of the, 544
New York, Devonian strata of, 453
—— Cambrian strata of, 489
—— Silurian strata of, 478
—— Laurentian strata of, 490
New Zealand, changes of level in, 149, 166
Niagara Limestone, fossils of the, 478
Nicaragua, gold veins in, 620
Nice, section of slanting beds near, 20
Nidau, iron tools in lake of, 126
Niger delta, extent of, 304
Nile, homogeneous mud of the, 132
—— stratified mud of the, 4
Ninety-fathom dike in coal, 67
Nipadites ellipticus, Sheppey, 247
Nodules in strata, how formed, 40
Noeggerathia cuneifolia, Permian, 383
Nomenclature of rocks, 117
—— of volcanic minerals, 498
Nordenskiöld on Greenland Cretaceous flora, 305
Norfolk cliffs, drift of, 170
North America. *See* America
Norway, Cambrian of, 488
—— foliation of crystalline schists in, 596
—— granite veins in gneiss of, 574
—— granite altering fossiliferous strata in, 581
Norwich or Fluvio-marine crag, 173
—— percentage of extinct shells in, 183
Nova Scotia coal-measures, 400
—— coal, reptiles and shells in, 406
—— folding and denudation of beds in, 110
Nucula Cobboldiæ, crag, 175
—— *Deshayesiana*, 224
Nummulitic formations, 260
Nummulites lævigata, Bracklesham, 213
—— *Puschi, Pyrenees*, 261
—— *variolaria, Bracklesham*, 242

OBOLUS Apollinis in Russian grit, 477
Obsidian, 505
Ocean, depth of, compared with height of land, 95
Oceanic areas, permanence of, 95
Ocellaria radiata in chalk, 275
Œningen, Upper Miocene beds of, 197, 199
—— insects of, 205
Oeynhausen, M. von, on Cornish granite veins, 561
Ogygia Buchii, 473
Oldhamia radiata—O. antiqua, 486
Old Red Sandstone, Upper, 436
—— Middle, with fish, 438
—— Lower, 442
—— trap of the, 548
—— classification of, 434
—— continental origin of, 435
—— dike cutting through, 578
Olenus micrurus, 483
Oligocene, term for Lower Miocene, 213, 227
Oligoclase, 498, 499
Oliva Dufresnii, Bolderberg, Belgium, 207
Olivine, 498, 501
Omphyma turbinatum, Silurian, 463
Onchus tenuistriatus, Silurian, 457
Oolite and Chalk, Palæontological break between, 324
—— classification and physical geography of the, 307
—— Great or Bath, 328
—— Upper, 309
—— Middle, 325
—— Lower, 328
—— plants of, 336
—— defined, 13
—— Inferior, fossils of the, 336
—— plutonic rocks of the, 572
—— and Lias, origin of the, 351
—— —— volcanic rocks of, 545
Oolitic strata, palæontological relations of, 338
Ophioderma tenuibranchiata, Lias, 314
Oppel on zones of Lias, 340
Orbigny, Alcide d', on foraminifera of Vienna basin, 208
—— on orbitoidal limestone, 262
—— on Pisolitic limestone, 268
—— on cretaceous nomenclature, 265
Oreodaphne Heerii, Italian Pliocene, 190
Orford, coralline crag of, 179

Organic remains, mineralisation of, 42
—— tests of age of strata, 102
—— tests of age of volcanic rocks, 522
—— disappearing under metamorphism, 582
—— geological provinces of, 104
Oriskany Sandstone, 477
Orthis elegantula, Ludlow, 458
—— *grandis*, Caradoc beds, 468
—— *tricenaria*, Bala beds, 468
—— *vespertilio*, Bala beds, 468
Orthoceras duplex, 473
—— *Ludense*, Silurian, 460
—— *laterale*, 431
—— *ventricosum*, Silurian, 460
Orthoclase, 498, 499
—— porphyry, 557
Orthoclastic felspars, 500
Osborne or St. Helen's series, Eocene, 238
Osteolepis, Old Red Sandstone, 440
Ostraceon, spine of, Bracklesham, 244
Ostrea acuminata, Fuller's earth, 336
—— *carinata, Chalk marl*, 283
—— *columba, Chloritic sand*, 283
—— *gregarea, Coral Rag*, 326
—— *deltoidea, Kimmeridge clay*, 322
—— *distorta, Middle Purbeck*, 310
—— *expansa, Portland sand*, 322
—— *Marshii, Oolite*, 338
—— *vesicularis, chalk*, 278
Otodus obliquus, Bracklesham, 245
Outcrop of strata, 60
Outliers of Old Red Sandstone, 437
Overlapping strata, 72
Owen, Professor, cited, 283, 301, 314, 370, 373
—— on Archæopteryx, 324
—— on Eocene Zeuglodon, 263
—— on footprints in Trias, 372
—— on fauna of Sheppey, 248, 250
—— on Gastornis Parisiensis, 260
—— on Labyrinthodon, 359
—— on mammalia of Stonesfield, 334
—— on Purbeck mammalia, 312, 314
—— on reptiles of coal, 406
—— on zoological provinces of extinct animals, 137
Owen, Dr. Dale, on Miocene of Nebraska, 232
Ox, tooth of (recent), 113
Oxford Clay, thickness and fossils of, 327

PAGHAM, erratic block at, 162
Palæaster asperrimus, 470
Palæchinus gigas, Mountain Limestone, 428
Palæocoma tenuibrachiata, Lias, 344
Palæoniscus, Permian fish, 379
—— *comptus, P. elegans, P. glaphyrus*, 380
Palæophis typhæus, Bracklesham, 244
Palæopteris hibernica, 437
Palæotherium magnum, 237
Palæozoic or Paleozoic, term defined, 100
—— plutonic rocks, 572
—— rocks, 455
—— type of corals, 426
—— series, 375
—— strata, thickness of, 75
Palagonia, dikes of lava in, 531
Paleolithic era, 124, 126
—— alluvial deposits of, 128
Palm in Swiss Miocene, 220
Palma, volcanic crater of, 496
Paludina lenta, Hempstead beds, 228
—— *orbicularis, Bembridge*, 236
—— *vivipara*, 31
Paradoxides Bohemicus, 487
—— *Davidis*, Lower Cambrian, 484
Parallelism of folded strata for long distances, 71
Paris basin, tertiary group first studied in, 118
—— tertiaries of the, 253
—— gypsum, fossil footprints in, 255
—— mammalia older than, 315
Parka decipiens, 'Old Red,' 444
Parkfield Colliery, ground plan of, 391
Patagonia, strata of, rich in soda, 587
Patella rugosa, Great Oolite, 332
Paterson, Dr., on monocotyledon of the coal, 424
Peach, Mr. C., cited, 605
—— Pteraspis, found by, 439
—— on Cardiocarpon, 423
Pearlstone, 505
Peat and shell mounds of Denmark, 124
Pebbles in mineral veins, 614
—— in chalk, 275
Pecopteris elliptica, coal, 414
Pecten Beaveri, White Chalk, 277
—— *cinctus, Neocomian*, 296
—— *islandicus*, Scotch drift, 156
—— *jacobæus*, in tertiary of Sicily, 188
—— *quinque-costatus*, 284
—— *Valoniensis, Rhætic beds*, 354
Pegmatite, 554
Penarth beds, 355
Pengelly, Mr., on Bovey Tracey lignite, 229
—— on flint-knives of Brixham Cave, 135
Pentacrinus Briareus, Lias, 344
Pentamerus Knightii, Aymestry, 458
—— *oblongus*, and *P. lirata*, 467
Pentamerus limestone, New York, 478
Pentland Hills, volcanic rocks of the, 519
Pentremites ellipticus, 428
Perched blocks, 147
Périgord cave, carving of mammoth in, 127
Permian, origin of name, 375
—— period, extent of land in, 382
—— volcanic rocks of, 546
—— Flora, 383
—— of Germany, 382
—— strata, thickness of, in north of England, 376
—— Upper and Middle, 376
—— Lower, 381
Perna Mulleti, Neocomian, 295
Petherwyn, Devonian fossils of, 447
Petrifaction, process of, 44
Petrophiloides Richardsoni, Sheppey, 348
Phacops caudatus, Silurian, 464
—— *latifrons*, Devonian, 446
Phalangista of Australia, 136
Phascolomys of Australia, 136
Phascolotherium Bucklandi, 335
Phasianella Heddingtonensis and cast, 43

Phillippi, on tertiary shells of Sicily, 187
Phillips, Professor, on fossils distorted by cleavage, 593
—— on terms Mesozoic and Cainozoic, 100
—— on thickness of coal-seams, 385
——on ninety-fathom dike, 67
—— on Wenlock limestone and shale, 463, 465
—— on Yoredale series, 386
Phillips, Mr. J. Arthur, on origin of gold of California, 620
Phillips, W., on composition of argillaceous rocks, 12
Phlebopteris contigua, Inf. Oolite, 337
Phlogopite, 498, 501
Pholadomya fidicula, Inf. Oolite, 337
Pholodomya cuneata, Thanet Sands, 253
Phonolite, 505
Phorus extensus, London Clay, 249
Phragmoceras ventricosum, Silurian, 460
Physa Bristovii, Middle Purbeck, 311
—— *columnaris*, 31
—— *hypnorum*, 31
Piedmont, absence of lakes in, 166
Pierre à Bot, huge erratic, 148
Pikermi, Miocene fossils of, 208
Pile dwellings of Switzerland, 125
Pilton, group of, Devon, 446
Pingle, Dr., on sinking of Greenland, 49
Pinnularia in Atlantic mud, 271
Pinus sylvestris in peat, 124
Pisolitic limestone of France, 268
Pitchstone, 505
Placodus gigas, Muschelkalk, 370
Placoids, rare in Old Red Sandstone, 440
Plagiaulax Becklesii, jaw and molar of, 313
Plagioclastic felspars, 500
Plagiostoma giganteum, Lias, 311
—— *Hoperi, Chalk*, 284
Plänerkalk of Germany, 276
Planes of stratification defined, 16
Planorbis discus, Bembridge, 236
—— *euomphalus*, 31, 238
Plants of Bovey Tracey, Miocene, 229
—— fossil freshwater, 31
—— of the Coal, 413
—— of the Lias, 351
—— of the Swiss Upper Miocene, 197
—— of the Oolite, 336
—— American Devonian, 452
Plastic Clay, Eocene, 250
Plas Newydd, rock altered by dike near, 514
Platanus aceroides, Miocene, 203
Platystoma Suessii, Hallstadt, 366
Playfair, on amount of subaërial denudation, 91
—— on faults, 65
Plectrodus mirabilis, Ludlow, 457
Pleistocene, term defined, 122
—— Period, stone implements of the, 127, 130
—— alluvial deposits, 128
—— extinct fauna of the, 129
—— climate of the, 138
—— mammalia, teeth of, 141
—— lakes of Switzerland, 164
Plesiosaurus dolichodeirus, Lias, 348
Pleurotoma attenuata, Bracklesham, 245
Pleurotoma exorta, Eocene, 33
Pleurotomaria anglica, and cast, 43
—— *carinata (flammigera)*, 429
—— *granulata, Inf. Oolite*, 337
—— *ornata, Inf. Oolite*, 337
Plieninger, Professor, on Triassic mammifer, 356
Pliocene glacial formations, 169–172
—— Period, 169
—— plutonic rocks, 570
—— strata of Sicily, 185
—— term defined, 120
—— volcanic rocks, 533
Pliopithecus of Sansan, 196
Plombières, alkaline waters of, 585
Plumbago of Massachusetts, 584
Plutonic and sedimentary formations, diagram of, 568
—— origin of the term, 551
—— rocks, Cretaceous, Oolitic, and Liassic, 572
—— Recent and Pliocene, 566
—— Miocene and Eocene, 569
—— uncertain tests of age of, 565
—— defined, 7
—— and volcanic rocks, connection, 558
—— Carboniferous and Silurian, 573
Podocarya Bucklandi, Oolite, 335
Poitiers and Rochelle, chalk area between, 289
Polypterus of the Nile, 439
Polyzoa of the coal, 427
—— and Bryozoa, terms explained, 178
Pomel, M., on fossil mammalia of the Limagne, 217
Ponza Islands, globiform pitchstone of, 512
Porites pyriformis, Devonian, 447
Porphyritic granite, 556
Porphyry, 505
Portland, Cycads in dirt-bed of, 318
—— section of, 319
—— oolite and sand, 321
'*Portland screw*,' a cast of a shell, 321
Porto Santo, marine shells in volcanic tuff of, 532
Post-Pliocene period. *See* Pleistocene
Post-Tertiary volcanic rocks, 524
Potamides cinctus, 32
Pothocites Grantonii, coal-measures, 424
Potsdam Sandstone, 489
Potstones in the chalk, 274
Pottsville, coal seams of, 391
Powrie, Mr., on Cephalaspis beds, 442
—— on Parka decipiens, 444
Pratt, Mr., on Eocene, Isle of Wight mammalia, 237
—— on Oxford Clay, 327
Pressure, solidifying rocks, 42
Prestwich, Mr., on Chillesford beds, 173
—— on Amiens flint implements, 129
—— on Macclesfield drift-shells, 161
—— on ice-borne erratic in coralline crag, 182
—— on Coalbrook Dale insects, 397
—— on Eocene strata, 250, 252
—— on faults in coal measure of Coalbrook Dale, 66
—— on shells of London clay, 237

Prestwich, Mr., on thickness of Coralline crag, 179
Prévost, M. Constant, on Paris basin, 253
Primary Limestone, 579
—— rocks, 455
—— series, 375
—— term defined, 100
Primitive rocks, a bad term, 9
'Primordial Zone' of Bohemia, 481, 487
Productus horridus, Permian, 378
—— *semireticulatus (antiquatus)*, 429
Progressive development indicated by low grade of early mammals, 374
Proteaceæ of Aix-la-Chapelle flora, 285
—— of Lower Molasse, Switzerland, 220
—— of Œningen beds, 201
Protogine, 578
Protosaurus of Thuringia, 380, 461
Provinces of animals and plants, 104
Psammodus porosus, 432
Pseudocrinites bifasciatus, Silurian, 464
Psilophyton princeps, Devonian, 452
Pteraspis in Lower Ludlow shale, 462
Pterichthys, Old Red Sandstone, 441
Pterodactyl of Kentish chalk, 281
Pterodactylus crassirostris, Solenhofen, 324
Pterygotus anglicus, 442
Ptychodus decurrens, White Chalk, 280
Pudding-stone or conglomerate, 12
—— formation of, 39
Pumice, 507
Punfield beds, brackish and marine, 303
Pupa muscorum, 132
—— *tridens*, Loess, 32
—— *vetusta*, coal, 408
Purbeck beds, Upper, Middle, and Lower, 309, 310, 317
—— fossil mammalia of the Middle, 311
—— marble, 310
—— subdivisions of the, 320
Purity of coal, cause of, 393
Purpura tetragona, Red Crag, 176
Purpuroidea nodulata, Great Oolite, 332
Puy de Côme, cone and lava-current of, 528
—— de Tartaret, lava-current and cone of, 527, 542
—— de Parion, crater of the, 529
Puzzuoli, elevation of land at, 526
Pygopterus mandibularis, Permian, 380
Pyramids built of nummulitic limestone, 261
Pyrenees, chalk altered by granite in the, 570
—— curved strata in, 63
—— lamination of clay-slate in, 598
—— nummulitic formation of, 261
Pyroxene group of minerals, 498, 501
Pyrula reticulata, Crag, 181

QUADRUPEDS, extinct, in Paleolithic gravels, 129
Quadrumana of Gers, 196
Quader-sandstein, cretaceous age of the, 276
Quarry-water in stone, 39
Quartz, glass cavities in, 555
—— porphyry, 557
—— vein, Christiania, 562
—— specific gravity of, 499, 554
Quartzite or Quartz Rock, 579
Queenaig, unconformable Palæozoic strata at, 89
Quenstedt on zones of Lias, 340

RADABOJ Miocene, brown coal of, 226
Radiolites foliaceus, White Chalk, 289
—— *Mortoni, White Chalk*, 278
—— *radiosa, White Chalk*, 289
Radnorshire, stratified trap in, 549
Rainprints with worm tracks in coal, 409
Ramsay Island, Cambrian of, 483
Ramsay, Professor, on break between Upper and Lower Cretaceous, 285
—— on breccias in Permian, 381
—— on continental origin of Permian, 382
—— on continental origin of Trias, 363
—— on denudation, 75
—— on escarpments, 81
—— on ice-erosion of lake-basins, 163
—— on lacustrine origin of Old Red Sandstone, 435
—— on Lingula Flags, 484
—— on Silurian metamorphic rocks, 603
—— on submergence in glacial period, 161
—— on Dundry Hill strata, 107
—— on thickness of the Lower Trias, 360
—— on thickness of Llandeilo beds, 473
—— on thickness of the Bala beds, 471
—— on volcanic tuffs of Snowdon, 549
—— on zones of the Lias, 340
Rastrites peregrinus, Llandeilo Flags, 472
Rath, Vom, on Tridymite, 499
Reading and Woolwich series, 250
Recent Period defined, 122
—— —— implements and fauna of the, 123–125
Record, imperfection of, in the earth's crust, 115, 256
Red crag, older Pliocene, 175
—— percentage of extinct species in, 183
—— oxide of iron colouring strata, 435
—— Sandstone, origin of, 362
—— Sea and Mediterranean, distinct species in, 104
Redruth mine, section of veins in, 609
Reindeer Period in South of France, 126
Relistran mine, pebbles in tin of, 611
Reptiles of the Lias, 347
Retepora flustracea, Permian, 377
Rhætic beds between Lias and Trias, 354
Rhine, freshwater strata of the, 29
—— loess of the, 131
Rhinoceros in drift of Abbeville, 131
—— *leptorhinus* (*megarhinus*), molar of, 142
—— *tichorhinus*, molar of, 142
Rhode Island, metamorphic rocks of, 584
Rhynchonella navicula, Ludlow, 458
—— *octoplicata, White Chalk*, 277
—— *spinosa, Inf. Oolite*, 337
—— *Wilsoni*, Aymestry, 459
Richmond, Virginia, triassic coal-field of, 372
Rigi and Speer, Lower Miocene of the, 218
Rimula clathrata, Great Oolite, 332
Rink, Mr., on Greenland land-ice, 151
Ripidolite, 498
Ripple-marked sandstone, how formed, 21
Rise and fall of land, 123

Rissoa Chastelii, Hempstead beds, 228
Rivers, denuding powers of, 78, 91
Roches moutonnées described, 147
Rock, term defined, 2
Rocks, altered by volcanic dikes, 514
—— altered by subterranean gases, 586
—— analysis of minerals in, 481
—— ancient, brought to the surface, 85
—— aqueous or stratified, 3
—— classification of, 98
—— four contemporaneous classes of, 9, 99
—— glacial scorings on, 147
—— great thickness of palæozoic, 87
—— metamorphic, age of, 599
—— metamorphic, defined, 8
—— plutonic, age of, 565
—— plutonic, defined, 7
—— solidification of, 38–42
—— underlying, not always the oldest, 99
—— volcanic, age of, 520
—— volcanic, defined, 5
Rock-salt of Trias, origin of, 362
Rogers, Mr. H. D., on blending of coal-seams, 391
—— on Virginian fault, 69
Rose, Gustavus, on isomorphism, 502
—— on Fifeshire dike, 547
—— on quartz in granite, 551
Rosso antico, red porphyry of Egypt, 506
Rostellaria (Hippocrenes) ampla, London clay, 249
Roth, M., on Miocene of Greece, 208
Rothliegendes of Germany, 382
Rudistes of the chalk, 279, 283, 290
Runn of Cutch, salt of, 364
Rupelian beds of Dumont, 225
Rupelmonde, Lower Miocene of, 224
Russia, chalk of, 270
—— Devonian of, 451
—— glaciation of, 154
—— Permian rocks of, 383
—— Silurian strata of, 476

SAARBRÜCK, reptiles in coal-field of, 397
Sabal Major, Lower Miocene, 220
Sables de Bracheux, 260
—— —— oldest tertiary mammifer in, 316
Sables moyens, Paris basin, 257
Sahlite, 501
St. Abb's Head, curved strata of, 52
—— unconformable stratification at, 71
St. Acheul, flint tool of, figured, 130
St. Andrews, carboniferous trap rocks of, 546
St. Bees Head, Permian of, 376
St. Cassian, fossil mollusca of, 366
—— and Hallstadt beds, 365
St. David's, Menevian beds of, 484
St. Helen series, Eocene, 238
St. Jean de Luz, curved strata of, 63
St. Petersburg, Silurian rocks of, 476
St. Peter's Mount, Maestricht beds of, 267
Salisbury, flint implement found at, 139
Salt, rock, origin of, 363
Salter, Mr., on fossils of Arenig group, 474
—— on Menevian beds, 484
—— on Tremadoc fossils, 482
San Caterina, undulating gypseous marls of, 63
Sandberger, Dr. F., on Mayence basin, 225
Sandstone, New Red, 354
—— Old Red, 434
—— slab of ripple-marked, 21
—— slab with cracks, 302
—— slab with footprints, 399
Sansan, Miocene vertebrata of, 196
Sao hirsuta, 488
Saurians of the Lias, 347
—— sudden destruction of, 319
Saurichthys apicalis, Rhætic Beds, 355
Saussure, on vertical conglomerates, 50
Saxicava rugosa, Scotch drift, 156
Saxony, beds of minerals in, 611
—— Cheirotherian footprints in, 360
—— Permian rocks of, 383
Scandinavia, glaciation of, 154
Scaphites æqualis, Chloritic marl, 282
Scapolite, 499
Scheerer on action of water in metamorphism, 585
Schist, term defined, 7
—— argillaceous, 579
—— hornblende, 578
—— mica, 579
Schimper, Prof., on Asterophyllites, 418
Schizodus Schlotheimi, Permian, 377
—— *truncatus, Permian*, 377
Schmerling, Dr., on Liége caverns, 133
Schwab, M., on Celtic coins in lake-dwellings, 126
Scoliostoma, St. Cassian, 366
Sconce, Bembridge beds at, 236
Scoresby, on Arctic icebergs, 151
Scoriæ, 507
Scotland, coal-fields of, 387
—— 'Fundamental gneiss' of, 492
—— mammoth in till of, 155
—— Old Red Sandstone of, 438
—— glaciation of, 155
Scotch drift, marine shells in, 156
Screws, fossil, internal casts of shells, 43
Scrope, Mr., on Isle of Ponza globiform pitchstone, 512
—— on minerals in lava, 524
—— on water in lava, 555
—— on Auvergne Miocene volcanoes, 542
—— on foliation of crystalline schists, 597
Scudder, Mr., on Devonian insects of Canada, 453
Sea, apparent fall of, caused by rise of land, 47
—— denuding power of the, 82
—— deep soundings in, 271
—— mean depth of the, 95
—— cliffs, inland, 80
Sea-urchin with crania attached, 25
Secondary and Tertiary, gap between the, 264
—— term defined, 100
Section of Auvergne alluvium, 77
—— of carboniferous rocks, Lancashire, 62
—— of chalk and greensand, 270
—— of concretionary nodules, 40, 41
—— of contorted drift, 158
—— of crags near Woodbridge, Suffolk, 179
—— of cross-stratification, 18–20
—— of curved strata, 52, 53
—— of curved strata of the Jura, 59
—— of dirt-bed in Isle of Portland, 319

Section of different forms of stratification, 18-20
—— of Forfarshire, showing curved strata, 51
—— of fossil tree, showing texture, 44
—— of folded and denuded carboniferous beds, Nova Scotia, 411
—— of the Oolitic strata, 308
—— of Recent and Post-Pliocene alluvial deposits, 128
—— showing creeps in coal-mines, 56
—— of slaty cleavage, 590
—— showing valleys of denudation, 75
—— showing the Weald formation, 298
—— of strata, thinning out, 17, 106
—— of superimposed groups at Dundry, Hill, 107
—— of unconformable junction of rocks, 71
—— of unconformable strata near Mons, 72
Sections illustrating faults, 65, 67, 68
Sedgwick, Professor, on the Cambrian Group, 480, 482, 485
—— on classification of Arenig group, 474
—— on concretionary structure, 40
—— on Devonian series, 434, 445
—— on garnet in altered rock, 515
—— on Magnesian Limestone, 376, 381
—— on position of the May Hill beds, 467
—— on slaty cleavage, 589, 592
Sediment, accumulation of, causing a shifting of the subterranean isothermals, 95
Selsea Bill, erratics at, 161
Sénarmont on action of water in metamorphism, 585
Sénonien of French cretaceous series, 266
Sequoia Langsdorfii, 221
'*Seraphim' head of Pterygotus anglicus*, 442
Serapis, raised beaches of, 123
Serpentine, 578
Serpulæ attached to *Gryphæa*, 24
—— attached to *Spatangus*, 25
—— attached to *Apiocrinus*, 330
Shale defined, 12
Sharpe, Mr. D., on American Silurian fossils, 479
—— on fossils distorted by cleavage, 593
Shell-mounds of Denmark, 123
Shells, arctic, in Scotch drift, 156
—— derivative, in the crag, 175, 185
—— marine, found at great heights above the sea, 5
—— of the Faluns, 194
—— proportion of living, in the crags, 174, 175, 180
—— value of, in classification, 119
—— fossil. *See* Fossils
Sheppey, fauna and flora of, 247
—— Eocene fish of, 248
Sherringham, erratic block at, 172
Sicily, fauna and flora of, older than the country itself, 189
—— great height of marine strata in, 48
—— newer Pliocene strata of, 185
—— subterranean igneous action in, 571
—— undulating gypseous marls of, 63
—— volcanic dikes of, 530
Sidlaw Hills, trap of, 540
Siebengebirge, brown coal of, 510
Sigillaria in coal-measures, 401, 419
Sigillaria lævigata, coal-measures, 419
Siliceous rocks, 11
—— limestone defined, 13
Silurian, derivation of the name, 455
—— granite of Norway, 574
—— metamorphic, of Highlands, 603
—— rocks, classification of, 455
—— strata of the continent of Europe, 476
—— strata of United States, 477
—— volcanic rocks, 549
Siphonotreta unguiculata, obolus grits, 477
Siwâlik Hills, freshwater deposits of, 209
Skaptar Jokul, flow of lava from, 523
Skye, hypersthene rocks of, 490
—— Isle of, syenite of the, 569
Slaty cleavage, 589
Slicken-sides, in opposite walls of veins, 610
—— term defined, 64
Smilax sagittifera, Œningen, 204
Smith, Mr. W., on White Lias bed, 354
Snowdon, volcanic tuffs of, 519
Soissonnais sands, 259
Solenastræa cellulosa, *Brockenhurst*, 240
Solenhofen stone, fossils in the, 323
Solent, Weald clay under the, 298
Solfatara, decomposition of rocks in the, 586
Somma, cone and dikes of, 526
Sopwith, Mr. T., models of outcrop of strata, 61
Sorby, Mr., on action of water in metamorphism, 585
—— on glass cavities in quartz, 555
—— on mechanical theory of cleavage, 593
—— on ripple-marks in mica-schist, 597
South Joggins, section of cliffs at, 401
Spain, Neocomian beds of, 304
Spalacotherium, Purbeck, 312
Spatangus radiatus, *Chalk*, 267
—— with serpula attached, 25
Speer and Rigi, Lower Miocene of the, 218
Speeton Clay, divisions of, 295, 296, 297
Species, gradual change of, 116
—— older than the land they inhabit, 189
—— similarity of conditions causing reappearance of, 294
Specific gravity of basalt and trachyte, 503
—— of volcanic minerals, 498
Sphenophyllum erosum, coal, 419
Spheroidal concretions in limestone, 41
—— Trap, 512
Sphenopteris gracilis, *Hastings sands*, 303
Sphærium (Cyclas) corneus, 30
Sphærexochus mirus, Silurian, 464
Sphærulites agariciformis, *White Chalk*, 289
Spicula of sponge, *Atlantic mud*, 271
Spirifer-sandstone of the Rhine, 450
Spirifera disjuncta, Devonian, 446
—— *alata*, *Permian*, 378
—— *mucronata*, 450
—— *trigonalis, and S. glabra*, 429
Spiriferina Walcotti, *Lias*, 342
Spirolina stenostoma, *Eocene*, 258
Spirorbis carbonarius, coal-measures, 396
Spondylus spinosus, White Chalk, 277

Sponge in flint from White Chalk, 279
Sponges, vitreous, in the chalk, 274
Spores and sporangia of coal, 404
Springs, mineral of Auvergne, 586, 606
Staffa, age of columnar basalt of, 540
Stalactite, origin of, explained, 134
Starfish in Silurian strata, 470
Stauria astræiformis, 426
Stereognathus of Stonesfield, 335
Sternberg, Count, on insects in coal, 396
Stigmaria attached to trunk of Sigillaria, 420
Stigmaria in coal-measures, 389, 402, 420
Stigmaria ficoides and surface showing tubercles, coal, 421
Stilbite, 499
Stiper-Stones or Arenig Group, 474
Stockwerk, assemblage of veins, 607
Stomata of Cretaceous Proteaceæ, 287
Stone weapons of Denmark and Switzerland, 124
Stonesfield slate, mammalia of the, 332
Strata, term defined, 3
—— alternations of freshwater, and shallow and deep-sea, 85
—— alternations of marine and freshwater, 35, 491
—— altered by intrusive granite, 581
—— apparent horizontality of inclined, 58
—— consolidation of, 38
—— contorted in drift, 158
—— contortion of, in Cyclopean Isles, 531
—— curved, inclined, and vertical, 50
—— diagonal arrangement of, 18
—— elevation of, above the sea, 47
—— general table of fossiliferous, 109
—— horizontality of, 16
—— how to distinguish marine and freshwater, 29–35
—— of organic origin, 27
—— origin of metamorphic, 580
—— outcrop of, 60
—— overlapping, 72
—— parallel folds of, 70
—— repeated by being doubled back, 64
—— slow growth of, attested by fossils, 23–26
—— tests of age of, 100
—— thinning out of, 17
—— unconformability of, 71, 114, 115
—— vast thicknesses of, not forming high mountains, 86–90
Stratification, diagonal or cross, 17, 20
—— different forms described, 15–21
—— joints and cleavage, section, 591
—— of metamorphic rocks considered, 582
Stratified rocks, composition of, 11
Striæ, production of, 146
Stricklandinia lirata, 467
Strickland, Mr., on thickness of the Trias, 358
—— on zones of Lias, 340
Striated pavements, 158
Strike, term explained, 57
Stringocephalus Burtini, 448
Stromboli, lava of, 567
Strophomena depressa, Wenlock, 464
—— *grandis*, 468
Strozzi, Marquis, on Pliocene flora of Italy, 190
Structure of coal, 403
Studer, Mr., on gneiss of the Jungfrau, 601
Subaërial denudation, 74
—— average annual amount of, 90
Subapennine beds, proportion of recent species in, 120
—— strata, Older Pliocene, 189
Submarine denudation, 81
Subsidence of land must preponderate over upheaval, 93
Subterranean heat affected by transfer of sediment, 9
Succinea amphibia, 31
—— *elongata*, 132
Suess, M., on fossils of St. Cassian beds, 365, 367
—— on Vienna basin, 207
Suffolk, crag of, 170
'Sunk country,' New Madrid, 393
Superga, Miocene of the, 208, 227
Superior, Lake, soft marl in, 40
Superposition of deposits, a test of age, 101
—— a test of age of volcanic rocks, 521
Sutherlandshire, unconformable Palæozoic strata in, 89
Swanage, fossil mammalia found at, 312
Sweden, Cambrian of, 488
—— ferruginous ores in lakes of, 363
—— slow rise of land in, 49
—— small thickness of Silurian strata in, 476
Switzerland, depth of lakes of, 164
—— lake-dwellings of, 125
—— Liassic insect fauna of, 351
—— Lower Molasse of, 218
—— Middle or Marine Molasse of, 206
—— Upper Miocene of, at Œningen, 197
Sydney coal-field, rainprints in, 409
Syenite, composition of, 557
Symonds, Rev. W. S., on Moel Tryfaen shells, 160
Synclinal and anticlinal curves, 51, 62

TABLE of Botanical Nomenclature, 287
—— of St. Cassian fossil mollusca, 367
—— of Cretaceous formations, 266
—— of Devonian series in Devon, 446
—— of divisions of Hastings Sand, 300
—— of English and French Eocene strata, 235
—— of formations succeeding the Cromer forest bed, 171
—— of ages of fossil vertebrata, 461
—— of Neocomian strata, 292
—— of mammalia older than Paris gypsum, 315
—— of marine testacea in the crag, 183
—— of Oolitic strata, 308
—— of volcanic minerals, 498
—— of Silurian strata of United States, 478
—— of botanical terms, 287
—— of Glacial and Post-glacial formations, 171
—— of Silurian rocks, 455
—— of Triassic strata of Germany, 364
—— of Cambrian strata, 481
—— of Permian of north of England, 376
—— of Welsh coal-measures, 386

Table of thicknesses of Carboniferous Limestone, 387
—— general, of fossiliferous strata, 109
Table mountain, granite veins in clay-slate of, 560
—— horizontal elevated strata of, 49
Tachylite, 504
Tails of homocercal and heterocercal fish, 379
Talc, 498
Talcose granite, 557
—— gneiss, 578
Tarannon shales, 466
Tartaret cone, and lava of, 527, 542
Tate, Mr., on St. Cassian fossils, 367
Tealby series, Middle Neocomian, 296
Teeth of extinct mammalia, 141
Tellina balthica (*T. solidula*), 170
—— *calcarea* (*T. proxima*), 157
—— *obliqua*, crag, 175
Temnechinus excavatus, 181
Temnopleurus excavatus, 181
Tentaculites annulatus, *Silurian*, 467
Terebellum fusiforme, *Barton*, 242
—— *sopita*, *Barton*, 242
Terebratula affinis, *Aymestry*, 459
—— *biplicata*, *White Chalk*, 277
—— *carnea*, *White Chalk*, 277
—— *digona*, *Bradford clay*, 332
—— *fimbria*, *Inf. Oolite*, 337
—— *hastata*, *Mountain Limestone*, 429
—— *sella*, *Neocomian*, 294
—— *Wilsoni*, *Aymestry*, 459
Terebratulina striata, *White Chalk*, 277
Terebrirostra lyra, *Chloritic Sand*, 284
Teredo navalis, boring wood, 26
Terminal moraines, 147
Tertiary formations, classification of, 114–117
—— plutonic rocks, 569
—— strata, subdivisions of, 120
—— terms defined, 100
Testacea. *See* Shells
Tests of the age of strata, 100
—— of volcanic rocks, 520–524
—— of plutonic rock, 565
Thallogens, 287
Thamnastræa, *Coral Rag*, 326
Thanet sands, 252
Theca operculata, Tremadoc beds, 482
Thecodontosaurus, *tooth of*, 362
Thecodus parvidens, Ludlow, 457
Thecosmilia annularis, *Coral Rag*, 326
Thirria, M., on Nerinæan limestone, 326
Thomson, Dr., on nummulites of Thibet, 261
—— Wyville, on Atlantic mud, 271
—— on depths of the sea, 95, 345
—— on sponges in chalk mud, 275
Three Rock Mountain, Ireland, drift of, 170
'Thrust' in coal-mines, 55
Thun, Lake of, land shells in strata near, 29
Thurmann, M., on Bernese Jura Oolite, 331
—— on structure of the Jura, 60
Thuringia, monitor of, 380, 461
Thylacotherium Prevostii, *Stonesfield*, 334
Tilgate Forest, fossil Iguanodon in, 360
Tilestones of the Upper Ludlow, 456
Till described, 144
Till mammoth in Scotch, 155
—— of North America, 162
Tin veins, age of, in Cornwall, 609
Titanoferrite, 499
Tithonian of the Continent, 292
Tongrian of Dumont, 240
Torbay, Devonian rocks of, 416
Torell, Dr., on ice-action in Greenland, 151
—— on shells of Scotch drift, 157
—— on Swedish Cambrian fossils, 488
Touraine, faluns of, 192
Tourmaline, 498
Trachytic rocks, 497, 504
—— tuff and porphyry, 505
—— lava, age of, 523
Transition Miocene mammalia, 209
Trap, term defined, 497
—— dike intersecting strata, 518
—— dikes, 512–515
—— intrusion of, between strata, 517
—— rocks, ages of, 520–550
—— tuff described, 507
Trappean rocks, nomenclature of, 496
—— rocks, their relation to active volcanos, 517
Trass of Lower Eifel, 535
Travertin, how deposited, 37
—— inférieur of Paris basin, 257
Tree ferns, *living*, 415
Trees erect in coal, Nova Scotia, 401
Tremadoc slates and their fossils, 481
Tremolite, 498, 501
Trenton limestone, fossils of the, 479
Trezza, volcanic rocks of, 530
Trias, beds of passage between lias and, 354
—— supposed continental origin of, 363
—— of England, 357–364
—— of Germany, 364–370
Trias, Saurians of the, 358
—— of the United States, 371
Triassic mammifer, 356, 373
Triclinic felspars, 500
Triconodon major in Middle Purbeck, 314
Tridymite, crystallised silica, 498
Trigonellites latus, *Kimmeridge clay*, 323
Trigonia caudata, *Neocomian*, 294
—— *gibbosa*, *Portland stone*, 322
Trigonocarpum ovatum, *and T. oliveforme*, coal, 423
Trigonotreta undulata, *Permian*, 378
Trilobites of Bala and Caradoc beds, 469
—— blind, 485
—— of Harlech grits, 486
—— metamorphosis of, 470
—— of primordial zone, 487
Triloculina inflata, *Eocene*, 258
Trimmer, Mr., on contorted strata, 159
—— on shells of Moel Tryfaen, 160
Trinucleus concentricus, *T. Caractaci*, 470
Trionyx, *carapace of*, *Bembridge*, 236
Triple group or trias, 357
Tripoli composed of diatomaceæ, 27
Trochoceras giganteus, Ludlow, 460
Trophon antiquum (*Fusus contrarius*), 177
—— *clathratum*, Scotch drift, 156
Tuff defined, 6
—— shelly, of the Grand Canary, 538
—— trappean of Llandeilo rocks, 473
—— shelly, of Gergovia, 542

Tunbridge Wells sand, 300
Tupaia Tana, *recent*, 333, 334
Turner, Dr., on chemical decomposition, 45
Turrilites costatus, *chalk*, 282
Turritella multisulcata, *Bracklesham*, 245
Tuscany, mineral springs of, 606
Tylor, Mr., on amount of subaërial denudation, 91
Tynemouth cliff, brecciated limestone of, 377
Tyndall, Dr., on slaty cleavage, 595
Tynedale fault, 67
Typhis pungens, *Barton clay*, 212

UNCITES, *Gryphus*, Devonian, 448
Unconformability of strata, 71, 115
Underlying, term applied to plutonic rocks, 10
Unger on American forms in Swiss Miocene flora, 205, 222
—— on Miocene plants of Croatia, 226
Ungulite, or Obolus grit of Russia, 477
Unio littoralis, 30
—— *Valdensis*, *Hastings Sands*, 302
United States, Cambrian of the, 489
—— cretaceous rocks of, 290
—— Devonian of, 451
—— Eocene strata in the, 262
—— footprints in Carboniferous of, 399
—— Lower Miocene of, 232
—— Older Pliocene and Miocene formations of, 210
—— Silurian strata of, 477
—— Trias of the, 371
Upheaval of land more than counteracted by subsidence, 93
—— power of denudation to counteract, 82, 92, 96
Upper Greensand, or Chloritic series, 282
Upsala, erratics on modern marine drift near, 154
Ural Mountains, auriferous alluvium of, 617
—— Uralite, 498, 501
Ursus, *spelæus*, *tooth of*, 143
Urville, Captain d', on size of icebergs, 152

VALLEYS, origin of, 79
Val d'Arno, Newer Pliocene of, 189
Valorsine, granite veins in talcose gneiss in, 599
Valvata piscinalis, 31
Vanessa Pluto, *Lower Miocene Croatia*, 226
Vaucluse, Miocene vertebrata of, 196
Vegetation. *See* Plants
Veins. *See* Mineral veins
Veinstones, 611
Venetz, M., on Alpine glaciers, 148
Venericardia planicosta, 243
Ventriculites radiatus, chalk, 275
Verneuil, M. de, on Russian Silurian, 460
—— on Permian flora, 383
Vertebrata, progress of discovery of fossil, 461
Vertical strata, 50
Vesuvius, Post-Tertiary volcanic rocks of, 525
Vesuvius, tufaceous strata of, 522
—— dikes of, 527
Vicarya Lujani Punfield, 303
Vicentin, columnar basalt of the, 511
Vienna Basin, Upper Miocene beds of, 207
Vine in Miocene beds at Œningen, 197
Virginia, eighty miles of fault in, 69
—— coal-field of, 372
Virlet, M., on corrosion of rocks near Corinth, 585
—— on cretaceous traps of Greece, 545
—— on fossils in veins, 611
—— on volcanic rocks of the Morea, 545
Volcanic ash or tuff, 507
—— breccia, 508
—— dikes, 512–515
—— force and denudation, opposing powers, 92
—— mountains, structure and origin of, 493
—— rocks defined, 5
—— mineral composition of, 497
—— Post-Tertiary, 524
—— Pliocene, 529, 533
—— Miocene, 536, 539
—— Eocene, 543
—— Cretaceous and Liassic, 545
—— New Red, Permian and Carboniferous, 545, 546
—— Old Red Sandstone, 548
—— Silurian, Cambrian, and Laurentian, 55, 549
—— rocks of Auvergne, 495, 541
—— columnar and globular structure of, 509
—— of Grand Canary, 538
—— special forms of structure of, 505
—— tests of age of, 520
Volcanos, extinct, 6, 541
Voltzia heterophylla, *Bunter*, 370
Voluta ambigua, *Barton clay*, 242
—— *athleta*, *Barton*, 242
—— Junonia, living, 177
—— *Lamberti*, coralline and red crag, 177
—— *Lamberti* faluns, 195
—— *nodosa*, *London clay*, 249
—— *Selseiensis*, *Bracklesham*, 245
Von Buch, Leopold, on 'elevation craters,' 495
—— on Silurian plutonic rocks, 573
Vosges Mountains, Trias of the, 370

WACKE described, 508
Wadhurst clay, 300
Wagner, M., on Miocene of Greece, 208
Walchia piniformis, *Permian*, 383
Wales and England, glaciation of, 159
Wales, slaty cleavage in, 590
Wallich, Dr., on Atlantic mud, 271
—— on chalk flints, 273
Walton crag, 176
Water, denuding power of running, 75, 92
—— action of, in metamorphism, 584
Waterhouse, Mr., on the mammalia of the Limagne, 217
—— on Stonesfield mammalia, 334
Water-stones of Cheshire, 362
Watt, Gregory, on fusion of rock, 584
Weald clay and its fossils, 298–300
—— section of, 298

Wealden area, thickness of the, 305
—— formation, 297
—— flora, 305
Webster, Mr. T., on Tertiary strata, 118
Wellington Valley caves, 136
Wener Lake, Silurian deposits of, 48
Wenlock formation, fossils of the, 462–466
—— limestone, 462
—— shale, 465
Werner on mineral veins in Saxony, 611
—— on isomorphism, 501
Westbury on Severn, Rhætic beds of, 355
Westwood, Mr., on lias beetles, 351
Wexford, veins of copper at, 617
Whitaker, Mr., on subaërial origin of escarpments, 81
Whitecliff Bay, Eocene of, 237, 241, 243
White or coralline crag, 178
—— sand of Alum Bay, 14
Whymper, Mr., on Arctic Miocene plants, 223
Williams, Mr., on Cornish lodes, 610
Williamson, Professor, on conifers of the coal, 422
—— on structure of calamite, 418
—— on spine of Ostraceon, 244
—— on Cheirotherian footprints, 360
Wind, denuding action of the, 74
Witham on fossil vegetables. 44
Wood drilled by mollusca, 26
Wood, Mr. Searles, on Bridlington shells, 170
—— on Chillesford and Aldeby beds, 171
—— on shells of the crags, 173, 174, 177, 180
—— on shells of crag and faluns compared, 194
—— on fish of Headon series, 239
—— table of marine testacea of the crag, 183
—— on thickness of coralline crag, 179
Wood, Mr. Searles, on classification of Weybourne sands, 171
Woodbridge, London clay at, 250
Woodward, Dr., on St. Cassian fossils, 367
—— Mr. H., on Pterygotus, 443
Woolhope beds, 465
Woolwich and Reading series, 250
Wright, Dr., on Barton shells, 241
—— on zones of the lias, 340
Wünsch, Mr. E. A., on trees in volcanic ash, 547
Wyman, Dr., on Alabama Zeuglodon, 263
Wyville, Thomson. *See* Thomson

XIPHODON gracile, Paris basin, 255
Xylobius Sigillariæ, Nova Scotia coal, 407

YOREDALE beds, thickness of the, 380
Yorkshire, Oolite of, 336
—— creeps in coal-mines of, 55
—— glacial drift of, 169
Young, Mr., on seeds washed out of mammoth tusks, 156

ZECHSTEIN of Germany, 382
Zeolites, secondary volcanic minerals, 499
Zeuglodon cetoides, Eocene, United States, 263
Zircon-syenite, 557
Zirkel, Professor, on intrusive rocks, 569
Zoantharia rugosa and *Z. aporosa*, 426
Zones of the lias, 340
Zonites priscus, coal, 408
Zoological provinces, great extent of, 103
Zoophytes, fossil, 24
—— *See* Corals, Bryozoa, etc.
Zurich, lake-dwellings in Lake of, 125

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